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U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TREC TECHNICAL REPORT 61-42

HIGH PERFORMANCE TANDEM HELICOPTER STUDY

VOL. 1 - SUMMARY REPORT

Task 9R38-13-014-01

Contract DA-44-177-TC-686

April 1961

prepared by:

THE VERTOL DIVISION
BOEING AIRPLANE COMPANY
Morton, Pennsylvania

$6.60

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HEADQUARTERS
U. S. ARMY TRANSPORTATION RESEARCH COMMAND
Fort Eustis, Virginia

FOREWORD

The report presented in the following pages is Volume 1, a summary report of the results of a high performance helicopter research program executed by Vertol Division, Boeing Airplane Company, for the U. S. Army. Volume 2, the design analysis, is in support of conclusions reported herein.

The U. S. Army, through the efforts of the Transportation Research Command (USATRECOM) at Fort Eustis, Virginia, has a series of programs underway to determine the gains that can be obtained in the performance of helicopters, both single rotor and tandem, through the utilization or incorporation of the latest design techniques.

This report which is the summary report presents the results of the research with regard to determining the increases in the performance of the tandem type helicopter, with particular reference to the Army HC-1B Chinook helicopter. The program takes into consideration not only the results of other related Army programs but also analytical data from private industry and other government agencies, such as the National Aeronautics and Space Administration.

The data have been presented to show gains that can be obtained in range and/or endurance, productivity and speed. An indication of components which are in production today and which could be utilized in the fabrication of a high performance tandem rotor helicopter is also presented.

The report has been reviewed in detail by USATRECOM and the recommendations and/or conclusions set forth in this report are concurred with. The results are quite encouraging and in many cases support the assumptions used frequently in design calculations. It is hoped that these results will arouse new interest or further the interest of all those desirous of improving the performance of helicopters in use today as well as those on the drawing boards of tomorrow.

FOR THE COMMANDER:

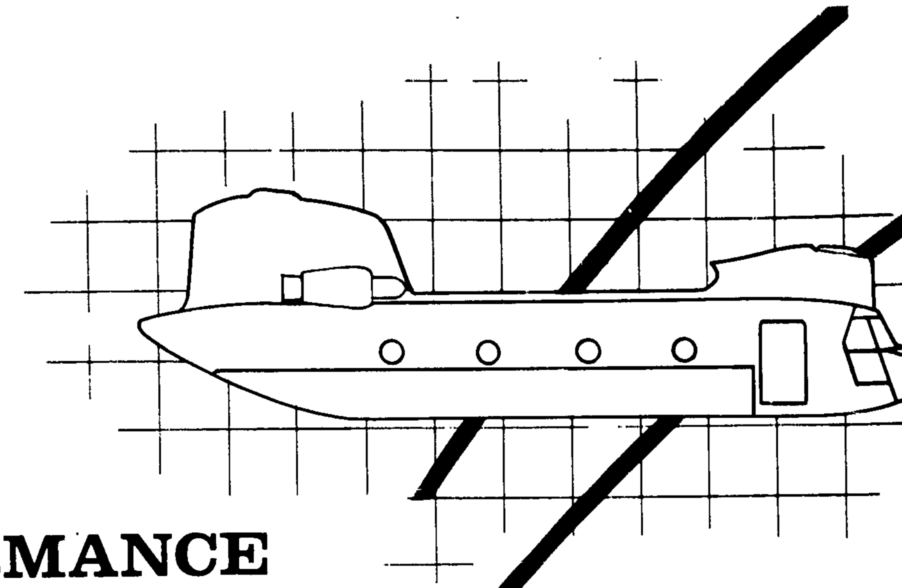
APPROVED BY:

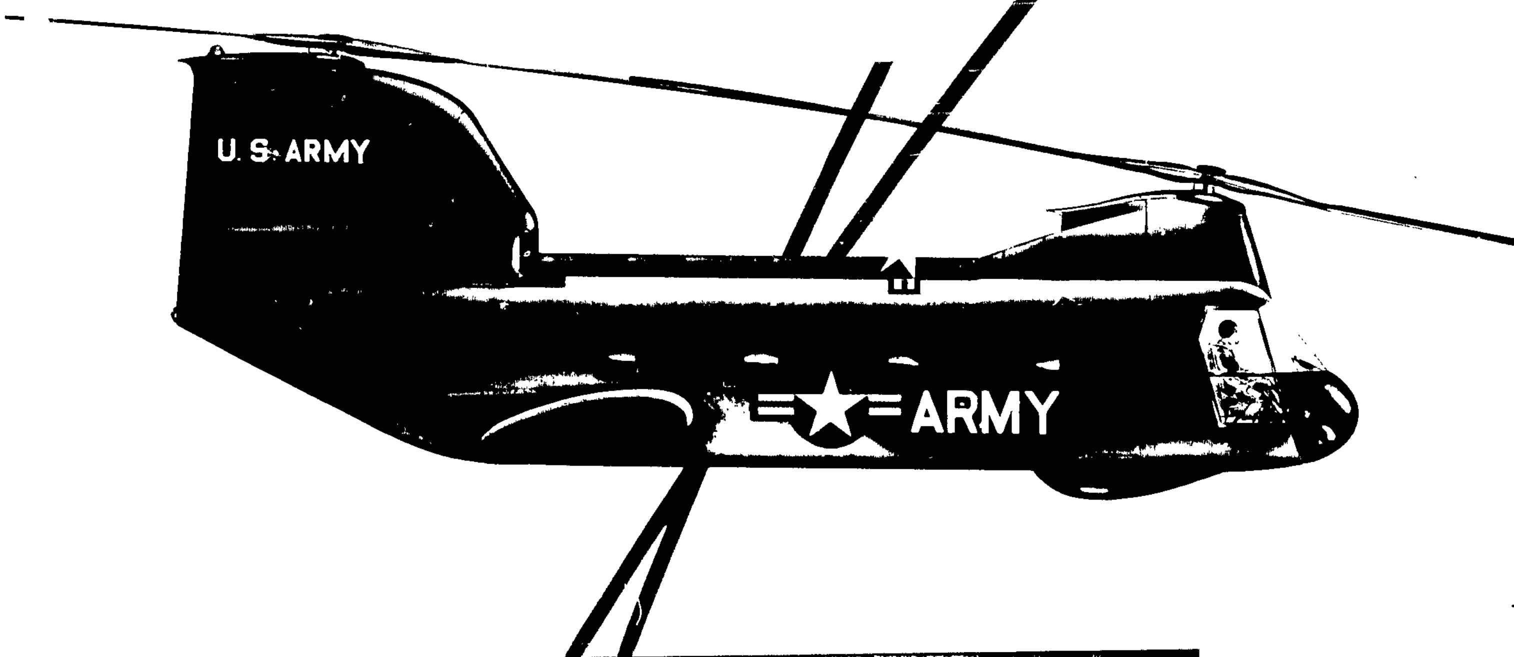
Robert D. Powell Jr.
ROBERT D. POWELL, JR.
USATRECOM, Project Engineer

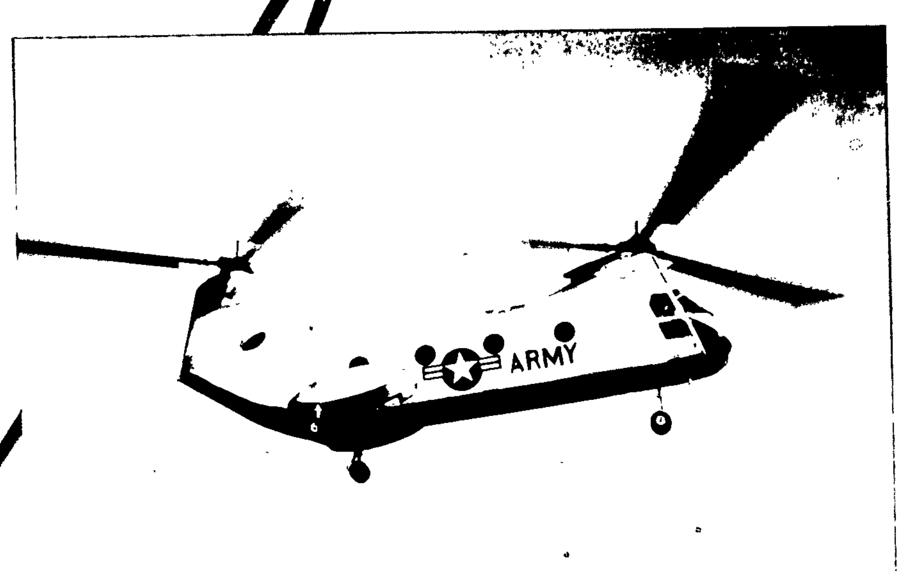
Earl A. Wirth
EARL A. WIRTH
CWO-4 USA
ADJUTANT

SUMMARY

HIGH PERFORMANCE HELICOPTER STUDY







January 27, 1961

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SUMMARY REPORT

HIGH PERFORMANCE HELICOPTER STUDY

TRECOM CONTRACT
DA-44-177-TC-686

VERTOL DIVISION
BOEING
MORTON PENNSYLVANIA

January 27, 1961 R 233

ACKNOWLEDGEMENTS

This study was accomplished by the Research and Preliminary Design Staff of the Vertol Division of Boeing Airplane Company. Notable contributions were made by the following personnel:

F. D. Harris - Project Aerodynamicist
N. Jeffrey - Aerodynamicist
F. Lentine - Aerodynamicist
G. Holcombe - Aerodynamicist
G. Donovan - Aerodynamicist
R. Swan - Weights
P. Leone - Aero-Elasticity
D. Hoffstedt - Rotor Design
F. Pallone - Rotor Design
C. Albrecht - Rotor Stress
R. Gable - Dynamics
J. Mayer - Rotor Controls

CONTENTS

LIST OF DRAWINGS

The Vertol Division of Boeing Airplane Company is pleased to present the results of its recent high performance helicopter studies conducted under Contract DA44-177-TC-686 for the U. S. Army Transportation Research and Engineering Command, Ft. Eustis, Virginia. Substantial increases in helicopter performance in terms of range, speed and productivity have been found feasible through modest advances in the state of the art applied to the YHC-1B, a U. S. Army inventory aircraft at relatively low development cost. It is concluded therefore, that the next generation of transport helicopters may be efficiently achieved through the normal evolution process concomitant to aircraft growth with accruing advantages in lead time and unit cost. The next step, amplifying these studies toward the realization of the high performance helicopter, would be the detailed design phase preparatory to actual fabrication.

SUMMARY

Requirements

In June 1960 the Vertol Division of Boeing Airplane Company received Contract DA44-177-TC-686 from the U.S. Army Transportation and Engineering Command to undertake a preliminary design study of a high performance helicopter. This report presents a summary of the analytical, test, and design effort. An additional report, "Design Analysis," Ref 1, presents these data in greater detail.

The aircraft to be designed was specified to be a conventional tandem-rotor helicopter configuration capable of meeting the following minimum requirements:

Ferry range	1600 n. mi
Speed	200 mph (174 kt)
Payload	800 lb
Flying qualities	per MIL-H-8501

Furthermore, it was stated that the design should emphasize the use of existing components, in whole or in part, which would not require further design, development, or extensive modification in order to minimize cost and elapsed time.

The Results

1. General Considerations

Vertol's analysis of the type of aircraft necessary to provide the Army with the required performance objectives was based upon a closely coordinated and correlated design and analytical investigation. Assessment of the findings takes into account the following factors:

a. The Army's primary need at this time is a large improvement in ferry range capability to enable self-transportability of tactical and logistic helicopters to the combat zone in the event of hostilities.

b. An increase in productivity (payload times forward speed) to insure a significant gain in operational missions and overall performance.

c. The desired results are to be achieved with minimum projections in the state of the art, either in design or analysis, consistent with the need for avoiding costly and time consuming development programs.

d. The helicopter's hovering efficiency is to be maintained. This implies no significant sacrifice in empty weight to gross weight ratio to achieve increased forward flight performance.

e. Significant gains in flying qualities, reliability and safety over the past few years are not to be compromised.

f. A minimum cost program is essential. Specifically, the following general criteria are observed:

(1) The development vehicle should make use of existing helicopter components wherever possible.

(2) Preferably this vehicle should be evolved from helicopters currently in the Army inventory.

2. High Performance Helicopter Configurations

Consistent with the above factors, the Vertol studies have shown that:

a. The attainment of the performance requirements is technically feasible with modest advances in state of the art.

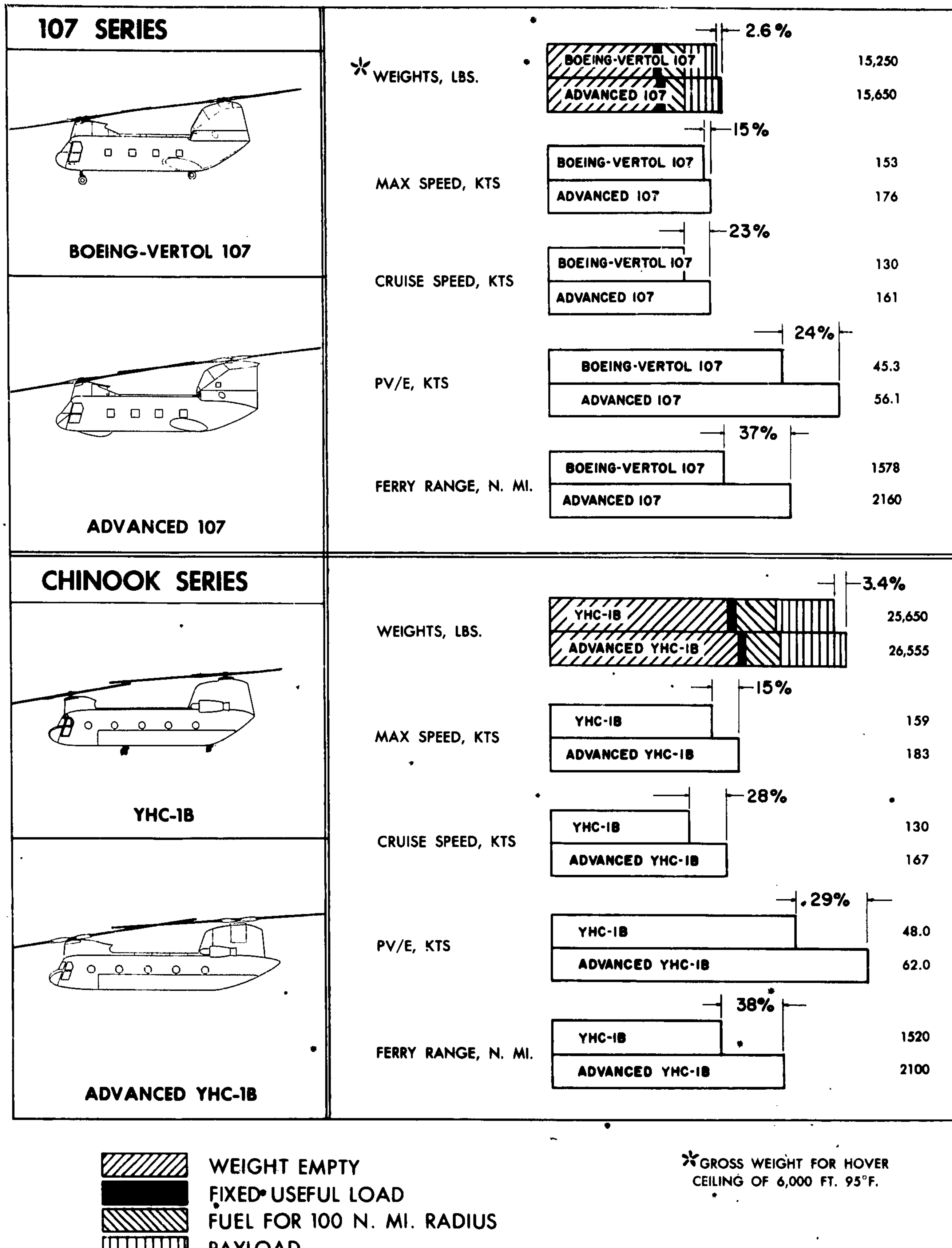
b. Modified versions of either the Boeing-Vertol 107 helicopter or the YHC-1B helicopter (Chinook), both U.S. Army aircraft, are capable of the required performance using present powerplants.

c. Principal changes to either aircraft are retractable landing gear, refaired aft end, faired hub and blade root, and a wider chord blade of extended radius.

3. Performance Potentials

The bar graph chart on the following page illustrates the potential performance gains employing either Boeing-Vertol 107 or YHC-1B Chinook helicopters. The presentation clearly indicates the following important points:

WEIGHTS AND PERFORMANCE



*GROSS WEIGHT FOR HOVER CEILING OF 6,000 FT. 95°F.

a. Without changing engines, and maintaining the empty weight to gross weight in a similar proportion, substantial performance improvements are possible. Comparing the Boeing-Vertol 107 and advanced 107, the maximum speed increases 15%, the cruise speed 23%, the productivity-to-empty-weight ratio 24% and the ferry range 37%. Similarly for the Chinook, the increase of maximum speed is 15%, cruise speed 28%, the productivity-to-empty-weight ratio 29% and ferry range 38%.

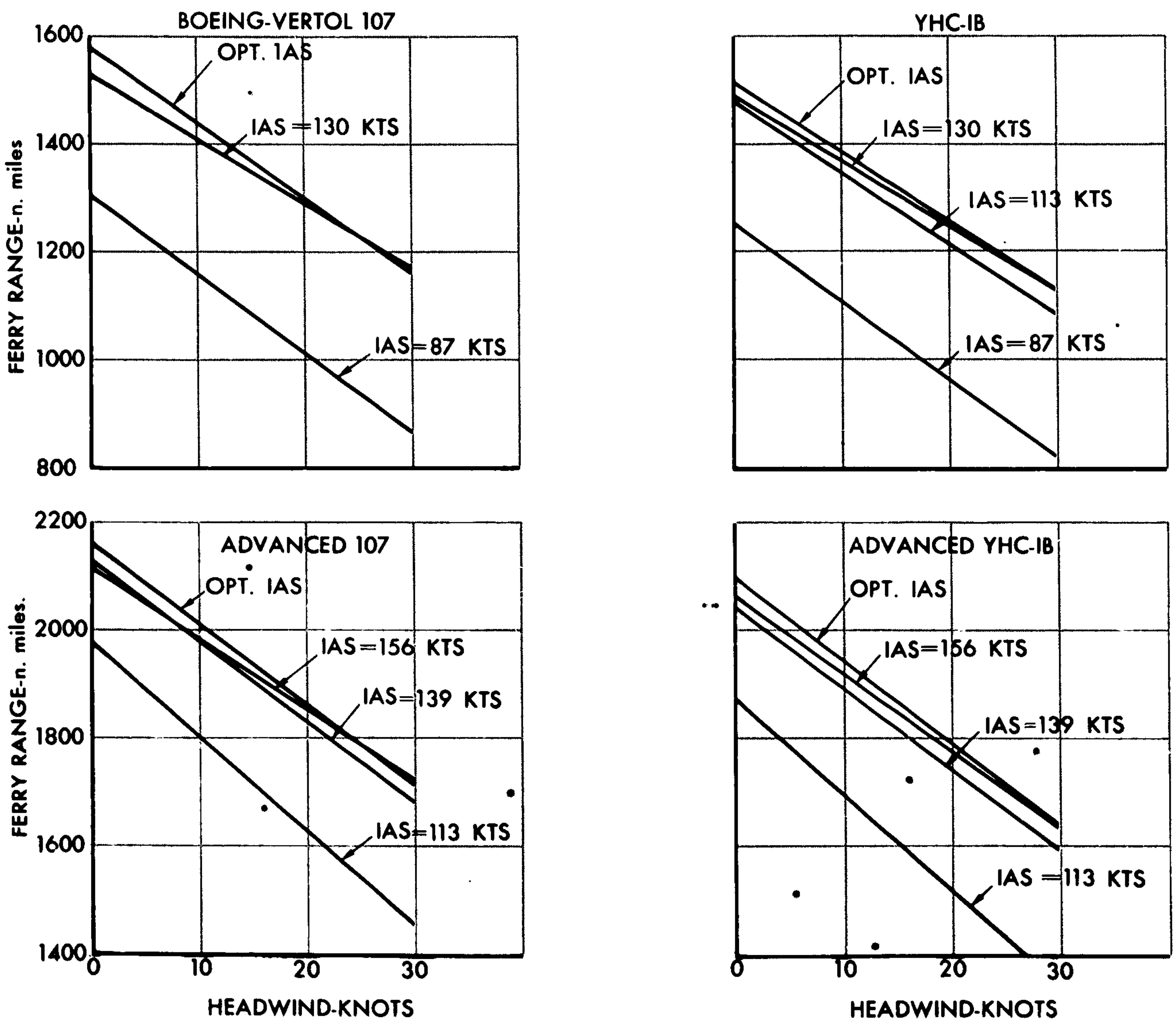
b. It is apparent that improvements in range, speed and productivity go hand-in-hand. This is a result of aircraft L/D improvements achieved through parasite drag reduction and rotor optimization. Thus the primary goal of increased ferry range is accomplished with added dividends in speed and productivity.

c. It is emphasized that these favorable results are achieved with no hover performance penalty. The four aircraft shown on the bar chart are shown at a gross weight determined by the hover ceiling of 6000 feet at 95°F requirement. Useful load is held at 5652 lb. for the Boeing-Vertol 107 series and 9512 lb. for the Chinook series.

4. Speed Effect on Range with Headwinds

The fortunate large increase in speed capability attendant with the range improvement has been found to enable a secondary improve-

EFFECT OF HEADWIND ON FERRY RANGE



ment in range performance when headwinds are present. This is illustrated by the graphs which follow, and occurs for these two reasons:

a. At constant airspeed the deterioration in ground speed (equal to the headwind) is a smaller percentage when the speed is initially higher at zero wind.

b. The decrease in ferry range associated with the ground speed loss at constant airspeed can be recouped to some extent by flying at a higher airspeed. This increment is always higher for the configuration whose zero wind cruise speed is the higher.

It is seen that the Boeing-Vertol 107 under a 30-knot headwind shows a 26% decrease in ferry range while the advanced 107 shows only a 20% decrease. Similarly for the Chinook, a 25% decrease is shown, with only a 21% decrease for the advanced Chinook. Thus the capability of high speed per se is advantageous for ferry range performance.

5. Productivity

Productivity (PV, payload times forward speed) is often employed as a criterion in comparisons of aircraft efficiency in transport applications. A more meaningful parameter, however, has been found to be the ratio of the productivity to empty weight (PV/E) as this is proportional to the ultimate economic criterion, ton/nautical miles per dollar.

The parameter, PV/E, is shown in the bar graph below:

a. PV/E optimizes at speeds close to maximum forward speed rather than best range speed. This effect, which is not commonly appreciated, means that best overall economy (maximum ton/nautical miles per dollar) is attained by consuming more fuel and flying as fast as possible. Explained in broad terms, higher speed means shorter time per ton of payload. Time saving in the final analysis means less dollars, both in operational cost per aircraft and in the number of aircraft required.

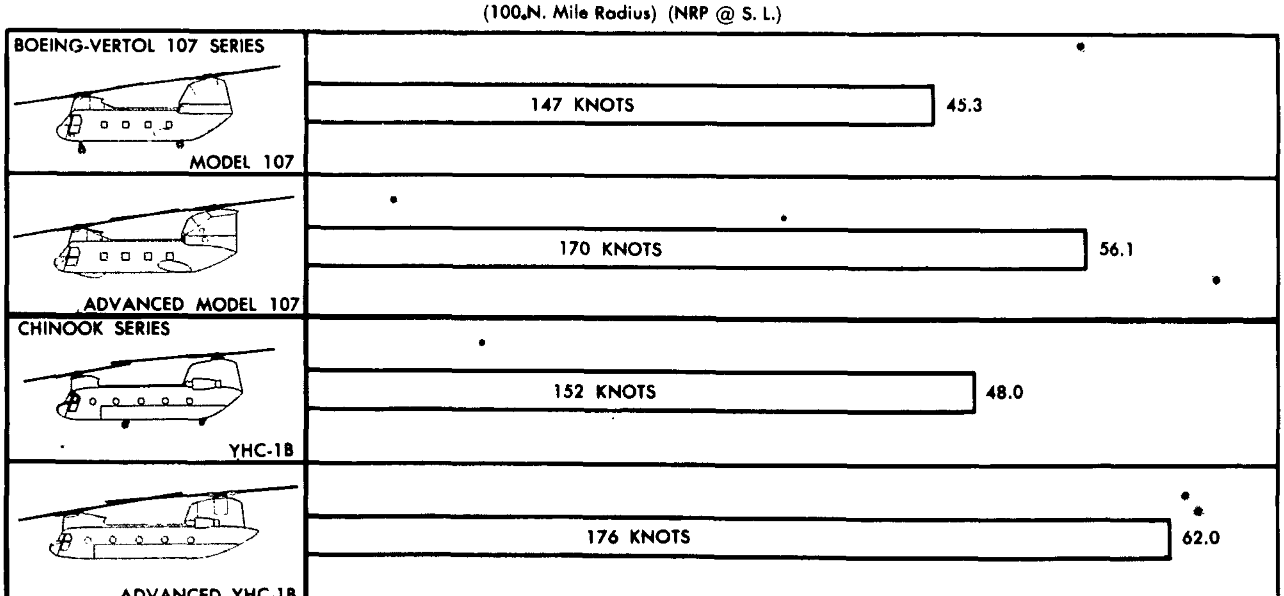
b. Comparing the present and advanced versions of the Boeing-Vertol 107, it is seen that the increase in speed capability results in a 24% gain in transport efficiency. A similar gain is shown at 29% for the advanced YHC-1B configuration.

6. Global Deployment

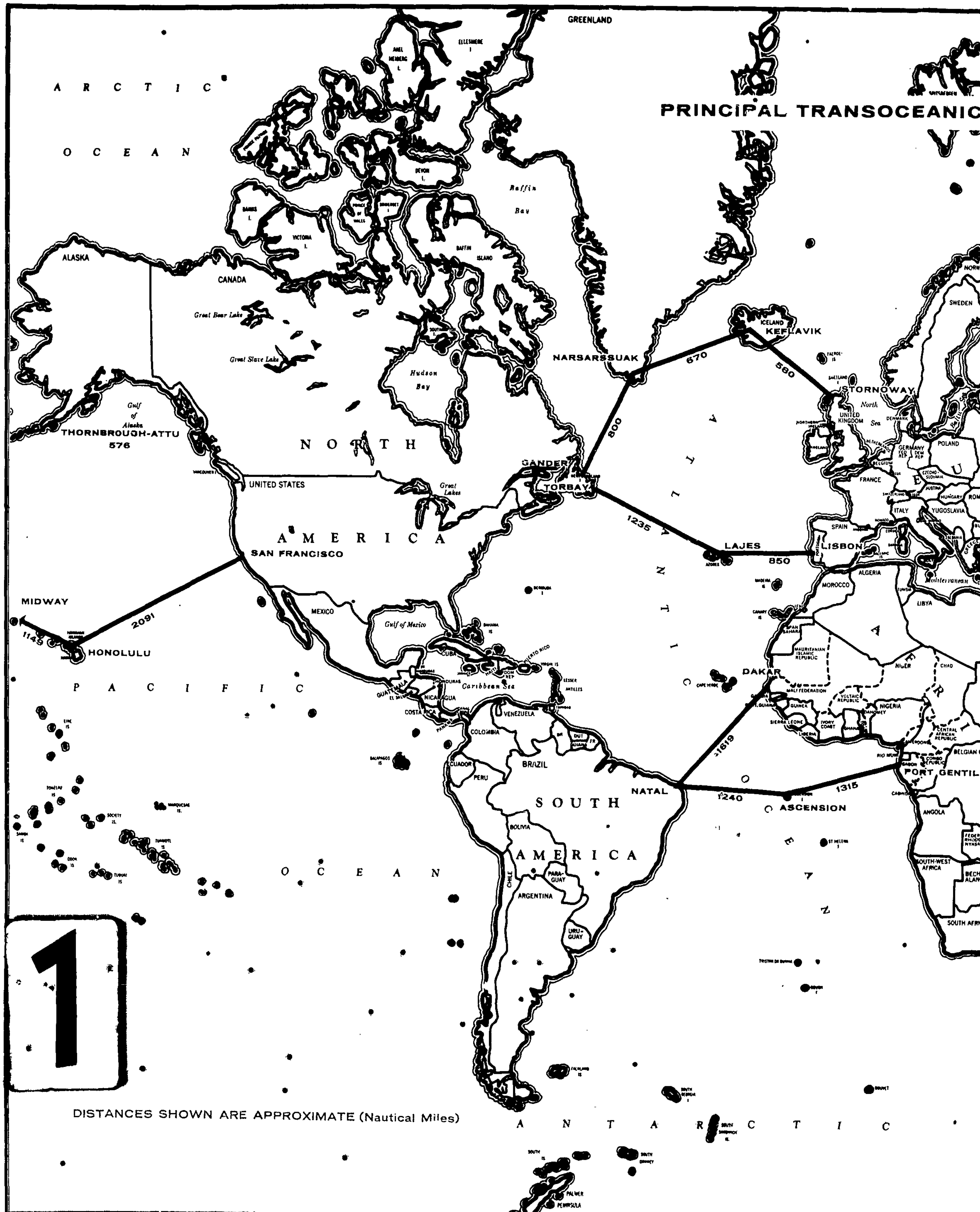
The advanced versions of the Boeing-Vertol 107 and YHC-1B, resulting from this study, are capable of global deployment without exception on any route. Thus, for the first time, instantaneous self-deployment of helicopters to "brush fire" conflicts become a real possibility, thereby achieving true Army air mobility. Principal transoceanic ferry routes are depicted on the map opposite. The largest stage is the San Francisco-Honolulu leg at 2091 nautical miles. The advanced 107 has a ferry range of 2160 nautical miles and the YHC-1B has 2100 nautical miles capability with one hour reserve. This amounts to a 13.3 hour flight which can be accomplished with a two-pilot operation.

PRODUCTIVITY—EMPTY WEIGHT RATIO

(100 N. Mile Radius) (NRP @ S. L.)

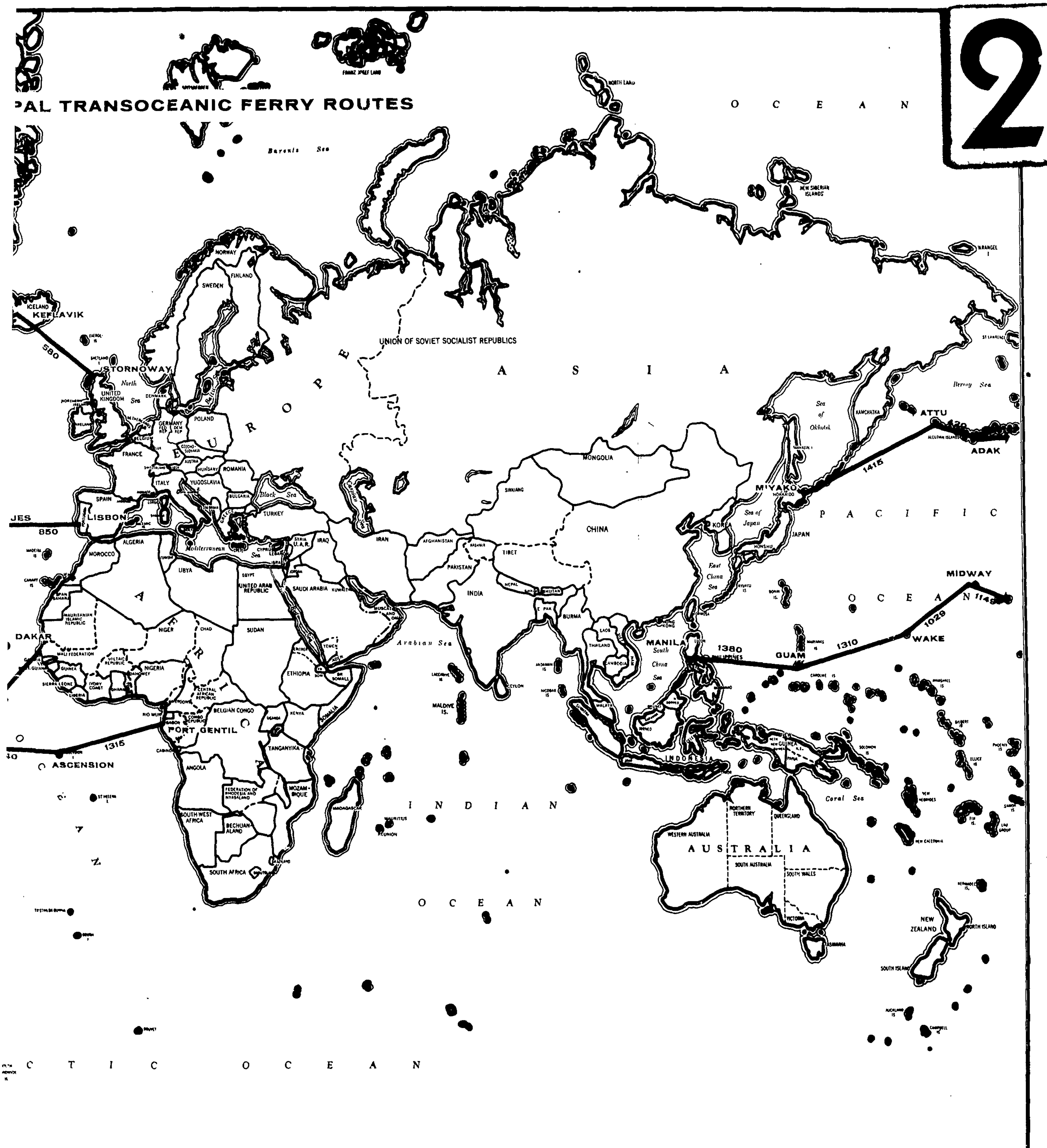


PRINCIPAL TRANSOCEANIC



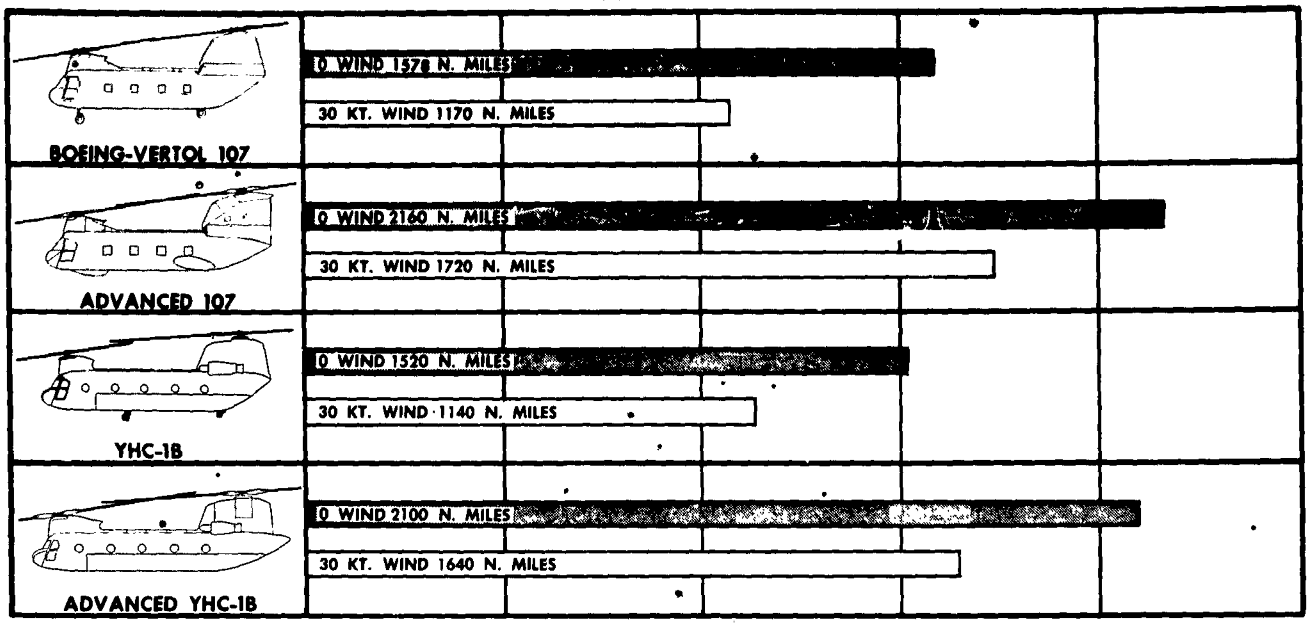
DISTANCES SHOWN ARE APPROXIMATE (Nautical Miles)

1



2
PAL TRANSOCEANIC FERRY ROUTES
KEFLAVIK
580
STORNOWAY
LISBON
850
DAKAR
PORT GENTIL
1315
ASCENSION
ATTU
ADAK
1415
MIYAKO
MIDWAY
1029
WAKE
1310
GUAM
1380
MANILA
E U R O P E
A S I A
A F R I C A
AUSTRALIA
UNION OF SOVIET SOCIALIST REPUBLICS
CHINA
MONGOLIA
INDIA
JAPAN
INDONESIA
NEW ZEALAND
O C E A N
P A C I F I C
O C E A N
I N D I A N
O C E A N
C T I C O C E A N
Barents Sea
North Sea
Black Sea
Mediterranean Sea
Arabian Sea
Sea of Okhotsk
Sea of Japan
East China Sea
South China Sea
Coral Sea
Bering Sea

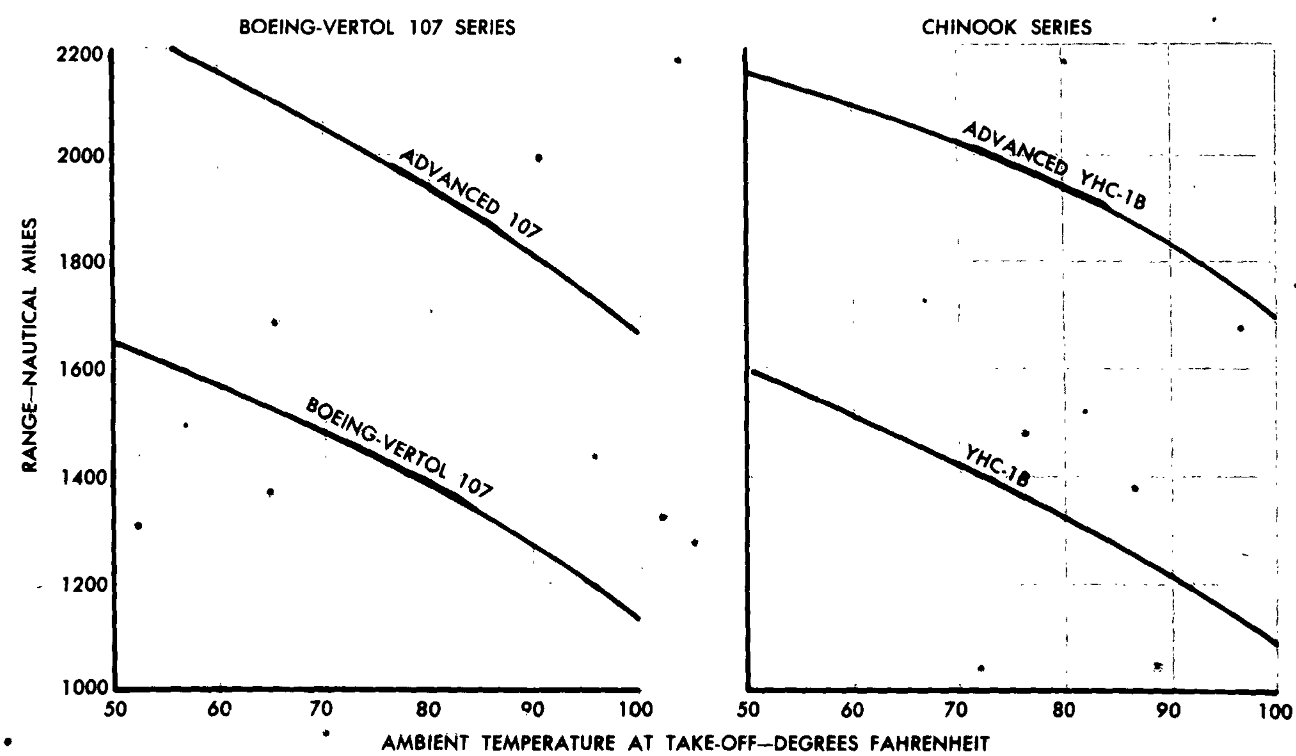
FERRY RANGE



It is important to note that both aircraft are capable of landing and flotation in sea state 3.

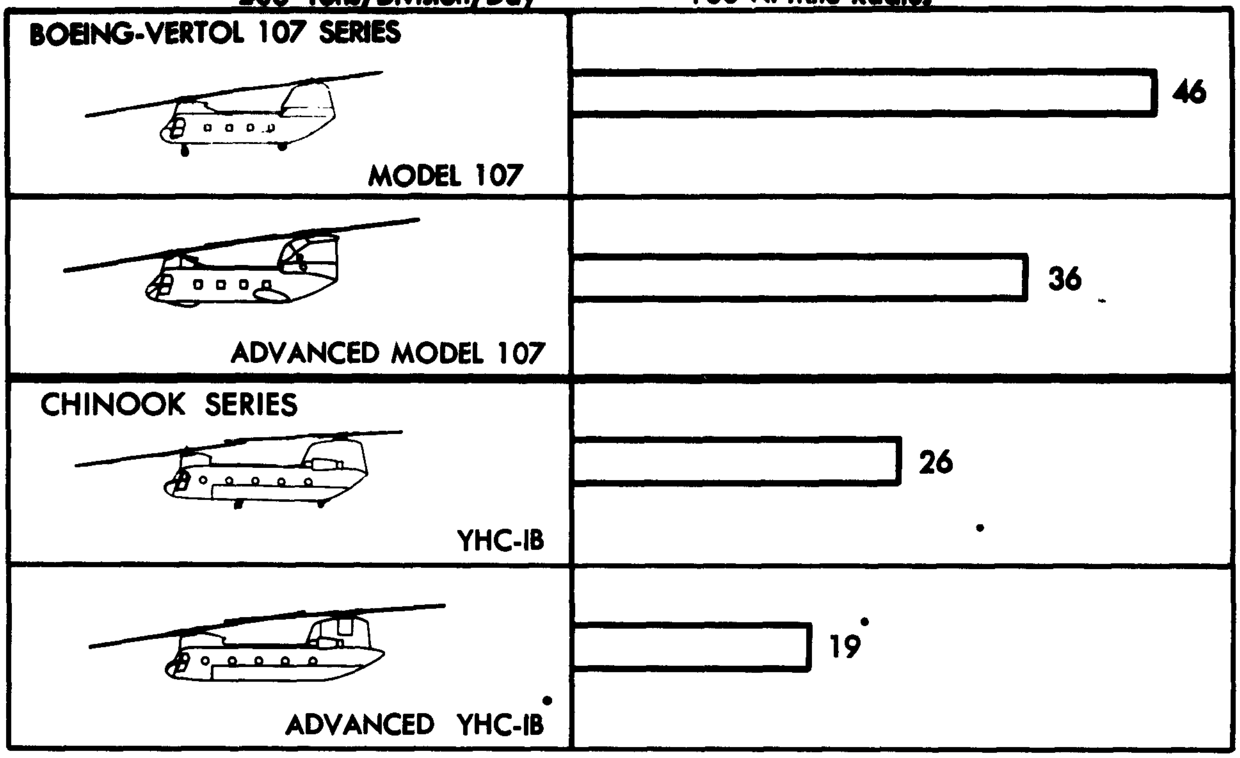
The effect of ambient temperature at takeoff on the zero headwind range is shown below for the Boeing-Vertol 107 series and Chinook series. Since the gross weight at takeoff is greatly affected by ambient temperature, through power available and the fuel available for cruise will be determined from the take-off conditions. Comparing the range at 100 degrees Fahrenheit with standard day range, it is seen that the Boeing-Vertol 107 shows a 28% decrease in ferry range while the advanced 107 shows only a 23% decrease. Similarly for the Chinook, a 28% decrease is shown with only a 19% decrease for the advanced Chinook.

EFFECT OF TEMPERATURE ON FERRY RANGE



NUMBER OF AIRCRAFT REQUIRED

200 Tons/Division/Day 100 N. Mile Radius



7. Logistics Support

The requirements for U.S. Army transport aircraft for the 1965-70 time period were the subject of recent industry-wide studies (ASR 3-60). Vertol's contribution, as reported in Reference 5, visualized the Boeing-Vertol 107 as applicable to the following missions in the combat zone:

a. Combat group tactical missions of 25 nautical miles radius, or less, within the combat zone from battle group area to FEBA.

b. Logistical resupply missions of 75 to 100 nautical miles radius from division rear to battle group area.

The YHC-1B capability was found relevant to these missions, plus longer range logistical resupply missions of 300 to 400 nautical miles radius.

The effect of performance improvements in these two aircraft on the numbers of aircraft required per Army division is shown in the previous chart for the short range logistical mission. As in ASR-3, a logistical resupply for the five battle groups of the division is assumed to be 40 tons per group, or a total 200 tons per division. Results of mission calculations assume an average usage of four hours per day for each aircraft in the total complement, based upon an availability of 67% of total aircraft and average usage of available aircraft of six hours per day.

The utilization of advanced 107 helicopters is seen to reduce the required number of aircraft from 46 to 36, or 21.8%. The advanced YHC-1B would permit a 27.0% reduction. These gains, which are presented as a measure of procurement requirements and hence lower cost, are a direct result of the improvement in speed capability.

Recommendations

1. Choice of Aircraft

It has been shown that either the advanced 107 or the advanced YHC-1B is capable of the performance requirements and could be used to demonstrate the feasibility of high performance. The concept, however, is certain to be applied mainly to production helicopters of the YHC-1B type for which the Army has a long term program. Cost studies indicate the overall high performance program costs would be significantly lower if the advanced

YHC-1B is selected for development. IT IS THEREFORE RECOMMENDED THAT THE ADVANCED YHC-1B CONFIGURATION BE ADOPTED AS THE DESIGN HIGH PERFORMANCE HELICOPTER.

2. Blade Size

Aside from the achievement of higher lift-to-drag ratios in forward flight, the ultimate high performance production version of the YHC-1B must maintain or exceed the required useful load capability at a design gross weight based upon hover out of ground effect at 6000 ft. at 95°F. This necessitates a decrease in required rotor power which may be achieved by a rotor radius increase from 29.5 feet to 30.8 feet. A slight lengthening of the fuselage is required and, hence, a small increase in silhouette will result. This change is structurally simple, however, and the fuselage length increment can be added at the present field splice. The radius increase is a minor effort since a new blade is required in any case to obtain the lower blade loading for forward flight. IT IS THEREFORE RECOMMENDED THAT THE REQUIRED BLADE AREA BE ACHIEVED BY A RADIUS INCREASE TO 30.8 FEET AND A CHORD INCREASE TO 26 INCHES.

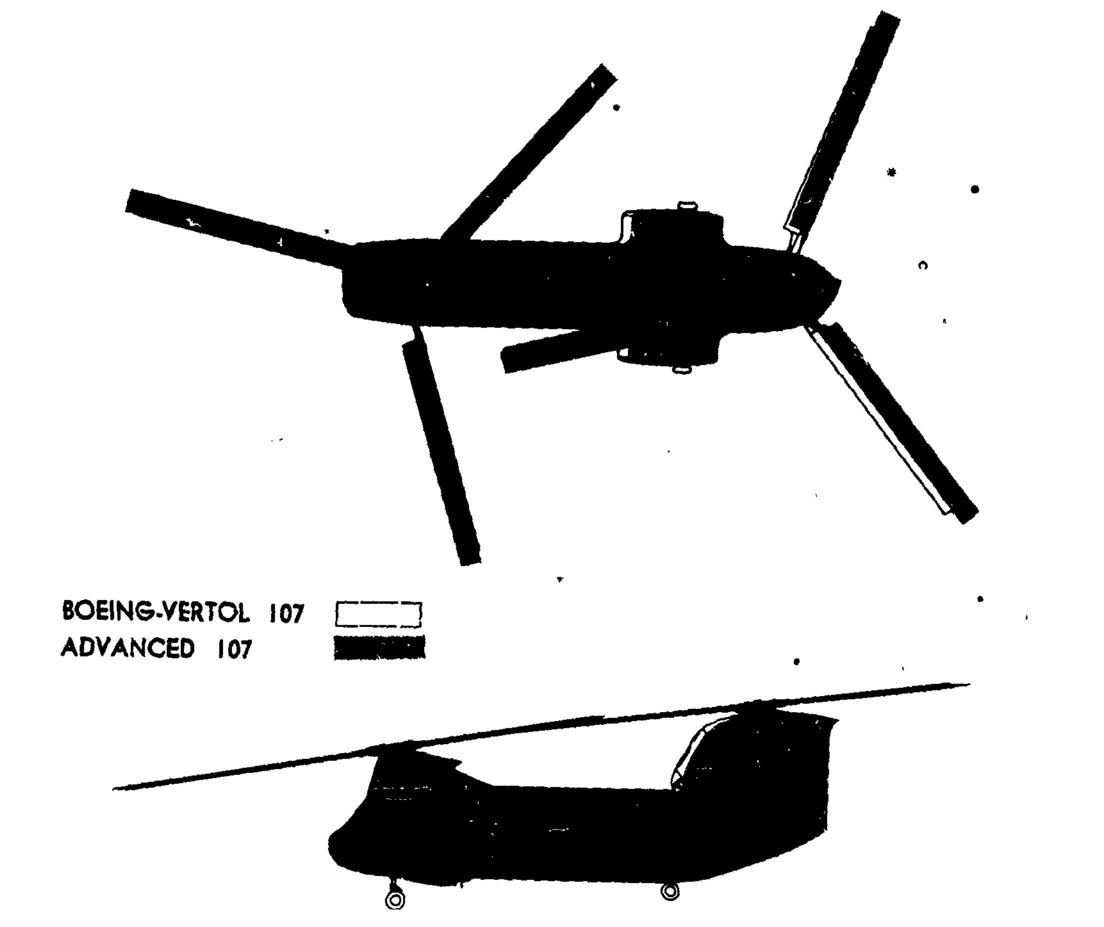
3. Plastic Blade

Vertol is developing at the present time an all-plastic blade for the YHC-1B helicopter. This design consists of unidirectional and crossply Scotchply (spar and skin materials respectively) and honeycomb filler. It offers several advantages: low development and manufacturing costs, ease of repair and maintenance, high structural damping, excellent airfoil control, surface smoothness, and adaptability to complex blade geometry (taper, twist, airfoil section).

This plastic blade is being designed to a 25 inch chord, 29.5 foot radius. By increasing the blade radius to 32 feet it would be suitable for an advanced YHC-1B.

4. Future Program

The high performance helicopter has been found to be technically feasible. The next step is the flight demonstration of this feasibility. IT IS THEREFORE RECOMMENDED THAT THE DETAIL DESIGN PHASE BE INITIATED ON THE ADVANCED YHC-1B HELICOPTER.



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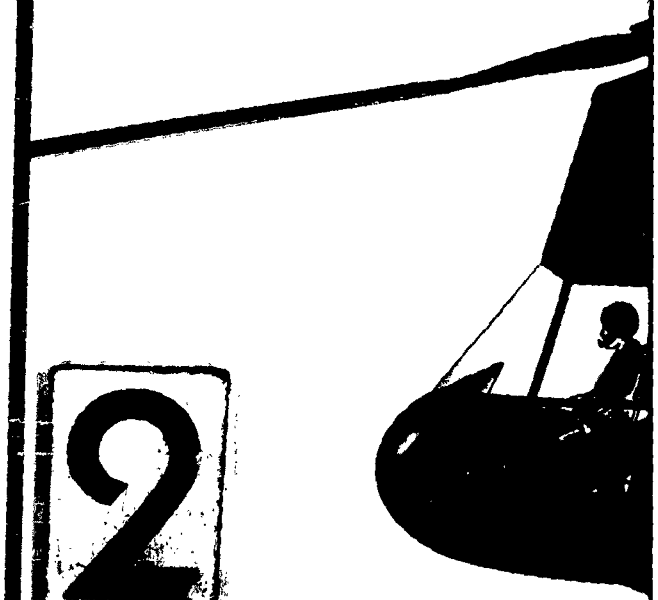
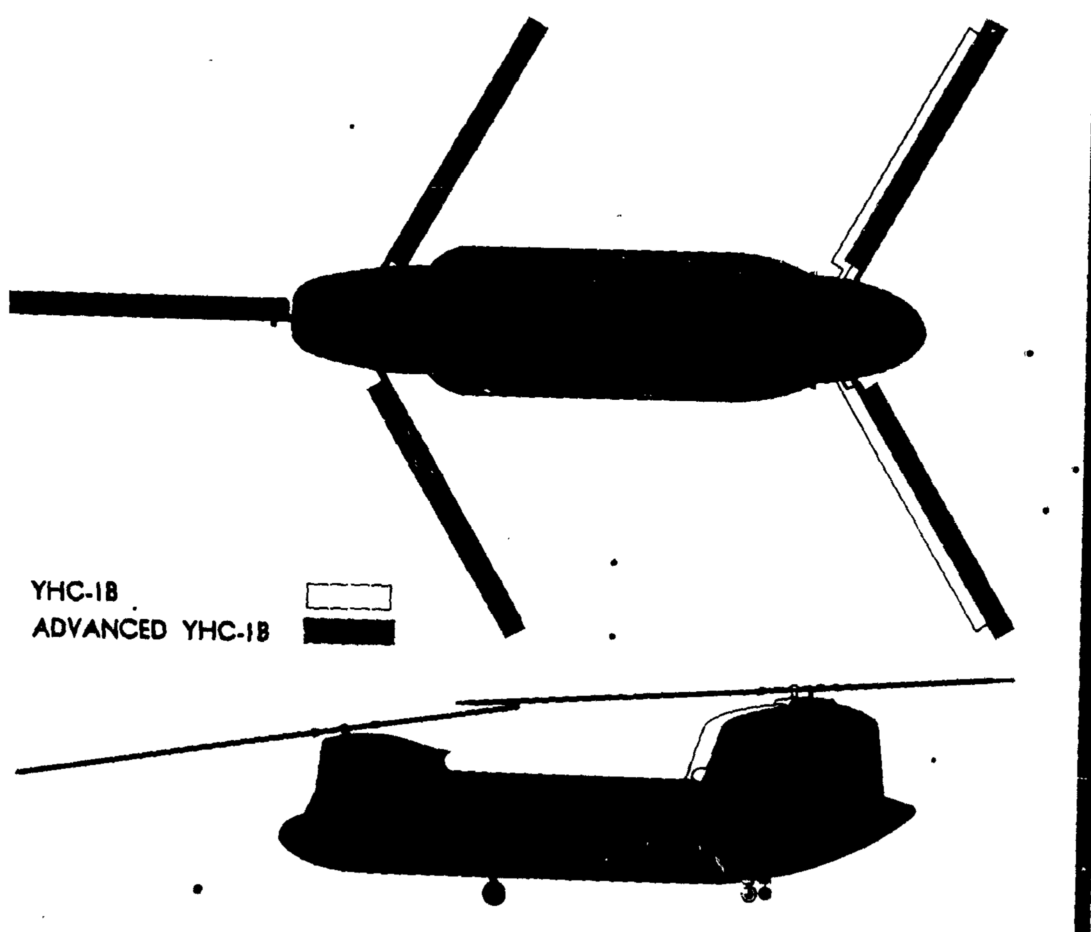
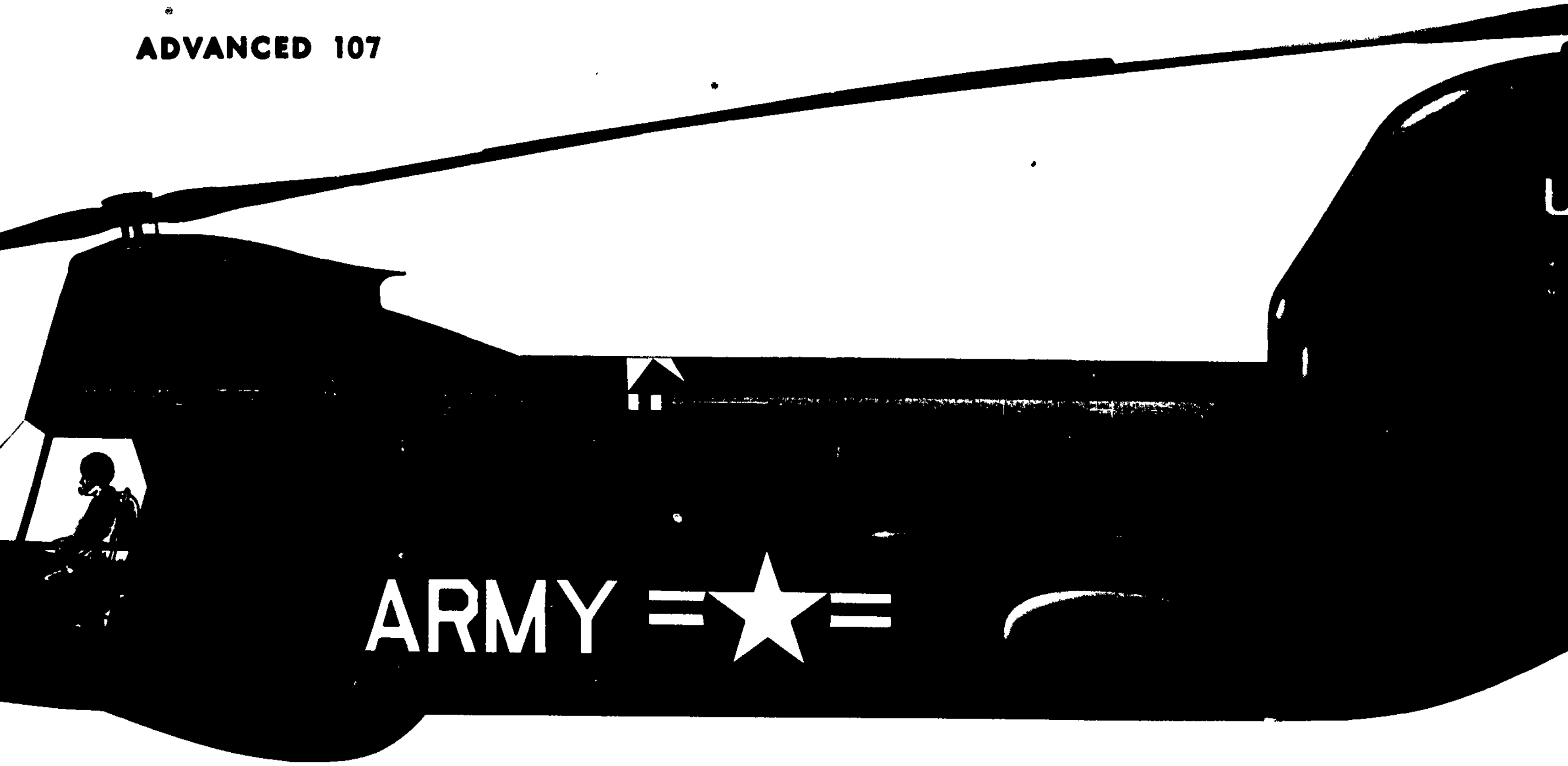
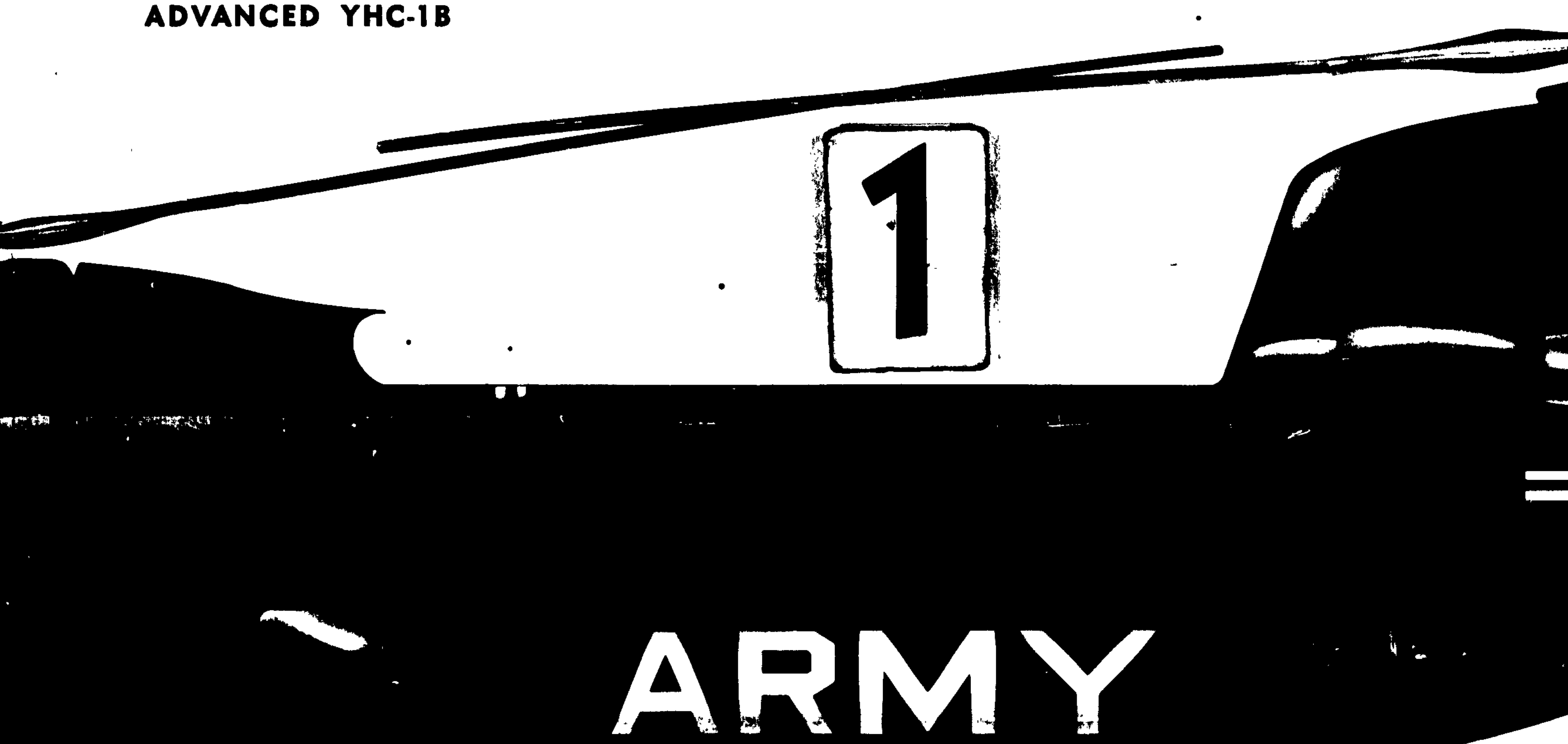


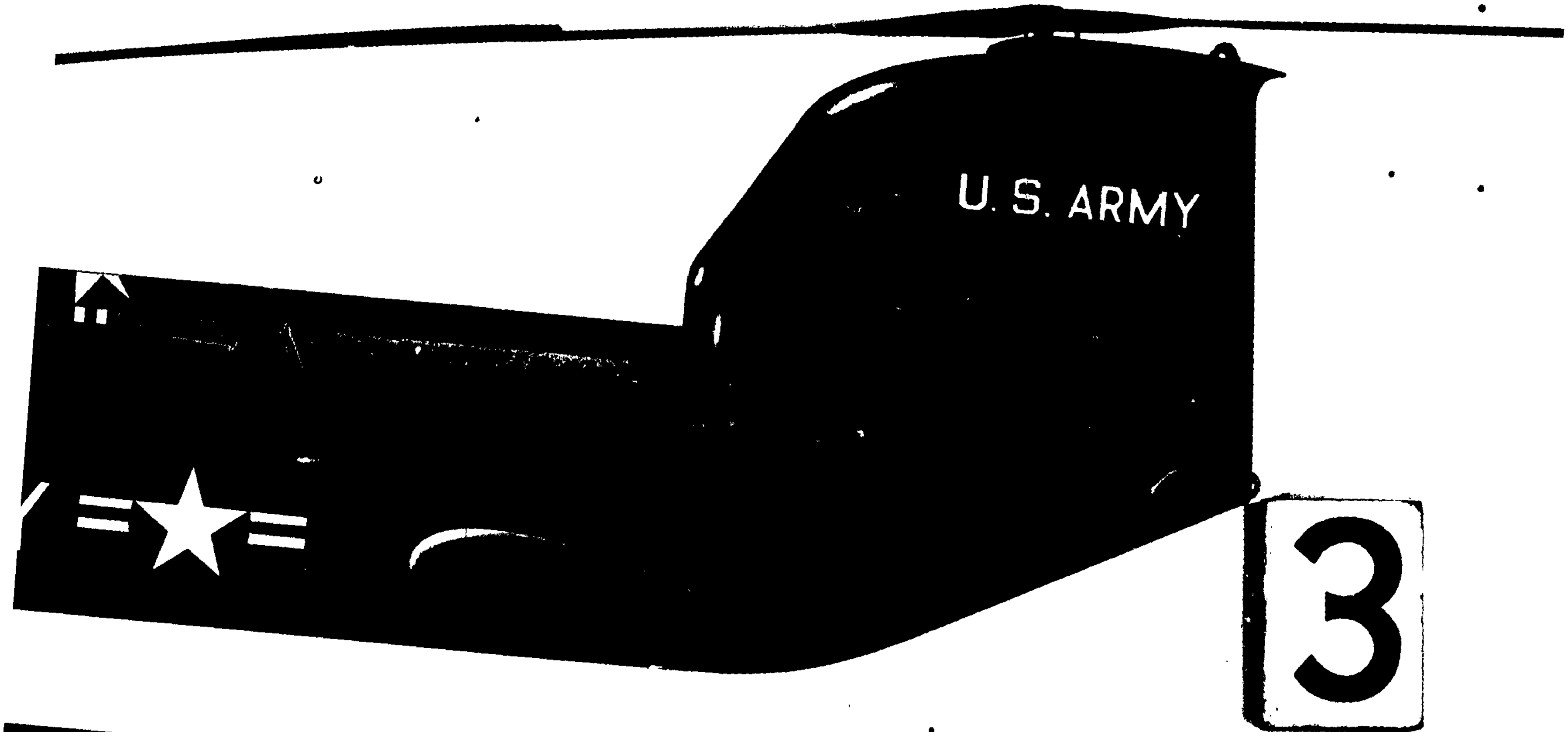


ADVANCED 107



ADVANCED YHC-1B

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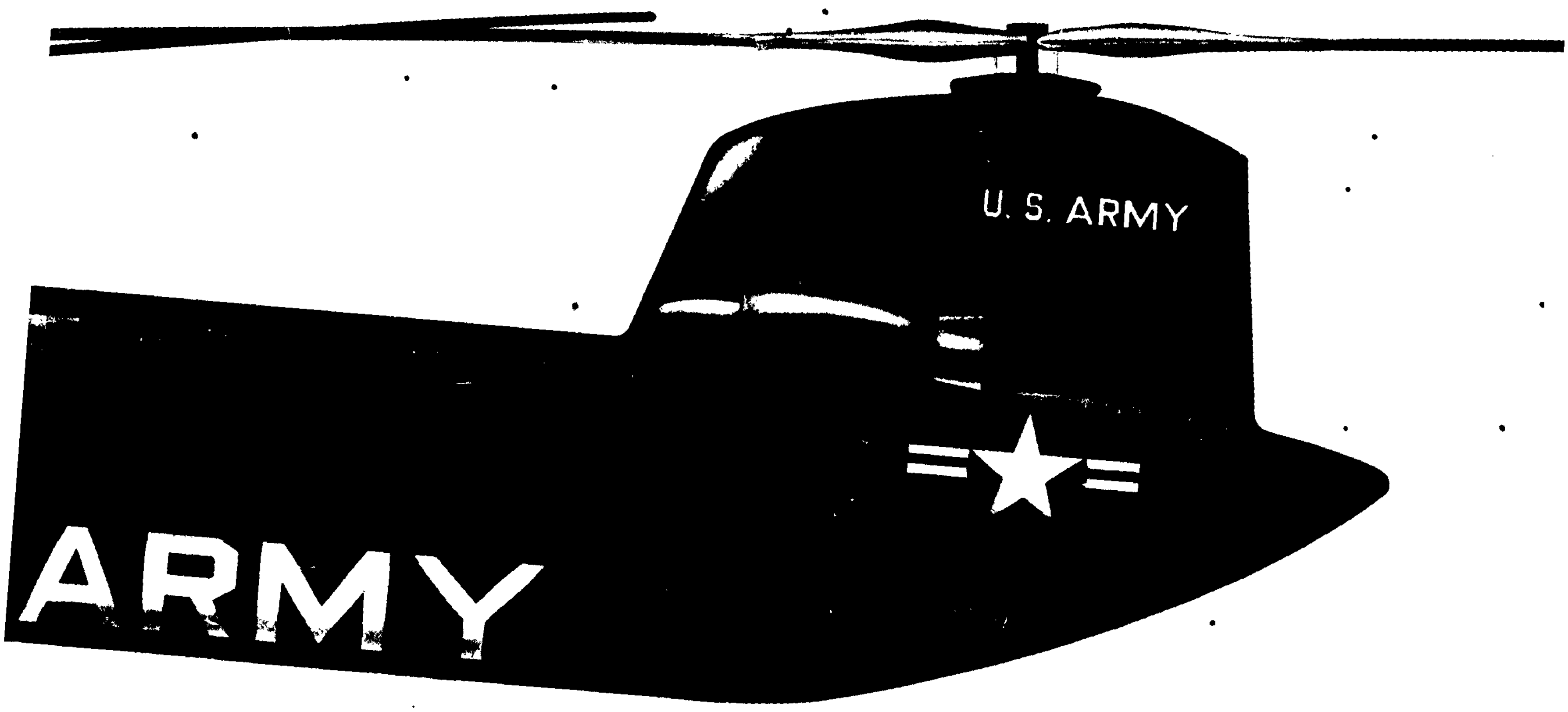
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INTRODUCTION

History of Program

In June 1960, the Vertol Division of the Boeing Airplane Company received a contract from TRECOM to undertake a preliminary design study of a high performance helicopter. The primary performance requirements for this helicopter were extended ferry range capability (1600 n.mi.) and speed (200 mph) without compromise in the present efficient hover and low speed characteristics. Furthermore, the design should employ existing components which would not require further design, development, or extensive modification in order to minimize cost and elapsed time.

In the conceptual phase, the goal of this design study was to be a research helicopter intended to demonstrate in-flight feasibility of the high performance capability. The original approach, as envisaged in the proposal, considered as examples either the use of the Boeing-Vertol 107 with cut-down Chinook blades or the use of the H-25 dynamic components with a new specially designed fuselage and cut-down H-21 blades.

The controlling item with respect to utilization of existing components is the selection of rotor blades. The performance requirements dictate the use of high blade area (low blade loading) which may be achieved by either using large-chord blades cut down in radius, or, for a given existing helicopter, to extend the radius and chord by modest amounts. Either of these means offer the advantage of proven structure and use of existing tooling.

To gain insight into the applicability of existing blades, a parametric study was undertaken, varying blade radius for a number of existing Vertol blades. To these families of blades was applied a forward flight criterion to determine allowable gross weights. Thus, a wide spectrum of high performance helicopters was examined and the best possible configurations were delineated. Blades utilizing the basic chord, airfoil and twist distribution of the H-25, H-21 and YHC-1A, Vertol-designed, Army-funded helicopters were investigated.

The parametric study confirmed the validity of the use of existing oversized blades to provide the lower blade loading requirement to demon-

strate high speed capability. As the parametric study progressed, it became apparent that application of reduced radius YHC-1B Chinook blades to the Boeing-Vertol 107 (YHC-1A) helicopter could fulfill the requirements of high performance. Furthermore, it was considered desirable to demonstrate the required high performance capability with an existing operational Army production type helicopter in order to avoid development cost of a single purpose research aircraft. Consequently, recommendations were made to discontinue further parametric investigation and proceed immediately to the preliminary design phase of the Boeing-Vertol 107 equipped with cut-down Chinook blades. The YHC-1B was not considered in the parametric study since there were no larger chord blades available.

The parametric study indicated that the 107 with reduced-radius Chinook blades would provide the desired ferry range requirement (1600 n.mi.) and, at reduced gross weight, the high speed capability (200 mph). This configuration was still not regarded as an acceptable operational aircraft, due to the reduced short-range payload characteristics caused by empty weight increases. The empty weight increase can be attributed primarily to the use of non-optimum blades from structural and dynamic design considerations. A 30-lb. tuning weight per blade was required to provide the proper natural frequency characteristics to reduce vibration response. The tuning weights, plus the use of a non-optimum blade structure, aggravate hub design. In summary, although this high performance version of the Vertol 107 could be tolerated as a research aircraft, it was considered more desirable to conduct this effort with an aircraft having full operational capability. Therefore, the next area of investigation was the optimization of high performance rotor blades from structural and dynamic considerations.

To show maximum application to Army mission requirements, the investigation was extended to the YHC-1B Chinook, as well as continued with the 107 (YHC-1A). The present silhouette of these aircraft was maintained by using high performance rotor blades with optimized blade chord, twist, and airfoil section for minimum weight. Rotor radius extension was then unnecessary. With the present power plant ratings, this configuration has the disadvantage of reduced short-range payload, if gross weight is based on a hover ceiling requirement. The most effective means for increasing the payload is to optimize the blade radius for the mission requirements. This approach allows the use of the existing airframe and propulsion system but requires the extension of blade radius by a modest amount. The results of these various efforts are summarized in the body of this report. Detailed analysis of each configuration is reviewed in Vertol Report R-234, "Design Analysis Report" (Reference 1).

Fundamental Considerations

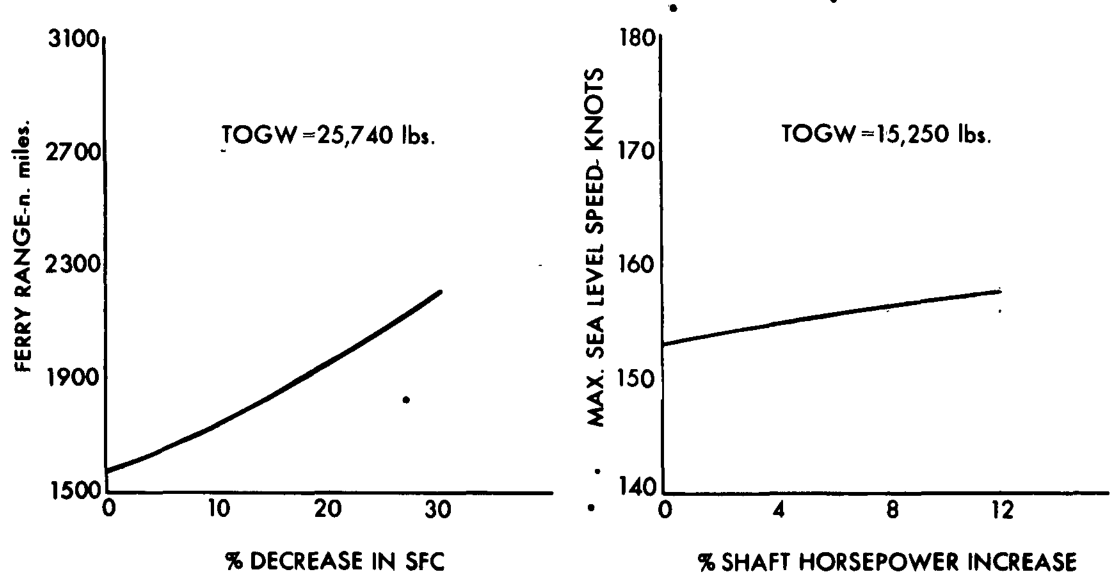
1. Ferry Range and Cruise Speed.

According to the contract, the principal performance goals of these studies were improved ferry range, productivity, and speed capabilities. The most important of these with regard to existing Army requirements is range, in view of the need for rapid global deployment. No requirement, outside that of this contract, appears to exist for speed per se. It will be shown however, that the optimum means to achieve range improvement inevitably leads to significant gains in both cruise and maximum speed.

The most important parameters for obtaining range improvement are engine specific fuel consumption and aerodynamic cleanliness of the aircraft. The most important parameters for increased speed are power loading and aerodynamic cleanliness. Possible improvements in engine characteristics, i.e. specific fuel consumption and available power, are insufficient in themselves to achieve the desired gains in range and speed as shown in the graphs below.

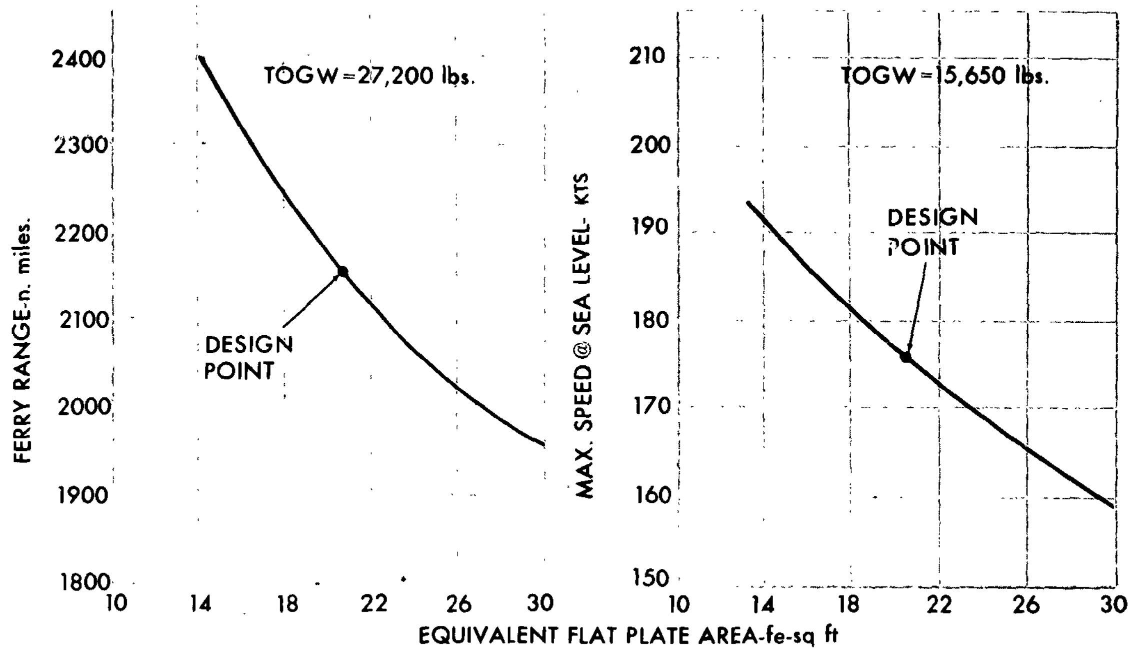
These plots show the effect of improved specific fuel consumption on ferry range and the effect of power increase on the maximum forward speed for the Boeing-Vertol 107 helicopter. An increase of 25% in ferry range would require a decrease of 21% in sfc. An increase in speed of 5 kts would require a power increase of 12% and would result in an intolerable degree of blade stall. Clearly such powerplant improvements are not achievable at any early date, if at all.

BOEING-VERTOL 107



On the other hand, readily obtainable aerodynamic drag improvement is seen to effect large increases in both range and speed as shown in the following graphs.

ADVANCED 107



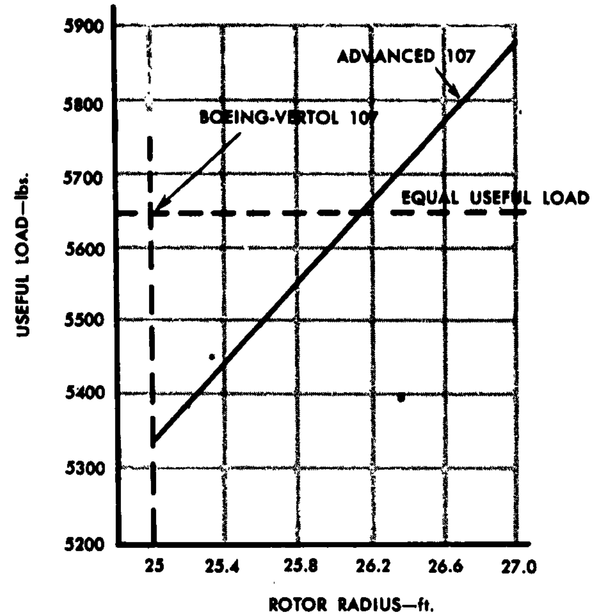
2. Payload and Productivity

The increase in empty weight, resulting from (1) the greater rotor weight and (2) structural changes necessary for drag clean-up, will result in decreased payload at short range at the same normal gross weight. Thus, the resulting increase in ferry range and speed capability is reduced by the decrease in short-range payload characteristics. This empty-weight penalty may be offset, however, by an increase in the allowable gross weight through an increase in rotor radius. Maintenance of equal useful load makes the zero-range payload of the high performance helicopter identical to that of the original aircraft and ensures higher payloads at finite range values. An accompanying gain in $\frac{PV}{E}$ is realized since the payload-to-empty weight ratio is essentially unchanged, and V, of course, is substantially increased.

The useful load recapture is illustrated by the following graph. The increase in blade radius required is quite small, 15 inches. This necessitates a fuselage stretch of 15 inches.

USEFUL LOAD VS ROTOR RADIUS

HOVER CRITERION: 6000 ft 95°F DAY



AERODYNAMIC CONSIDERATIONS

Introduction

To achieve the required advancements in ferry range and speed, principal attention and effort was devoted to aerodynamic studies. Emphasis was placed both on increases in aircraft L/D and on careful investigation of the rotor aerodynamic environment. This was necessary in order to rationally choose the physical blade parameters required to achieve optimum L/D and to avoid stall in the higher speed regime envisioned for the high performance helicopter. Such a study involved consideration of applicable airfoil sections, drag divergence near the advancing blade tip, stall at the retreating blade tip, reversed flow loadings, and blade root fairings. Most of this analysis was based on the results of an extensive computing program performed on a Boeing Aero-Space Division IBM 704 computer.

Wind tunnel drag reduction programs were conducted during this period on both the advanced 107 and YHC-1B configurations at the University of Maryland wind tunnel. Emphasis was placed upon hubs, afterbodies, pylons, fuel pods, and nose enclosures. A special program to investigate the hub fairing problem was conducted, using a one-third scale powered model of the YHC-1B hub. Since complete gear retraction is envisioned, no wind tunnel testing was required in this area and the concept required only design considerations.

The results of the aerodynamic study program indicated the feasibility of the high performance helicopter concept. It appears that all the pertinent aerodynamic factors are well within the present realm of understanding. A modest advance in the state-of-the-art is all that is required; no major breakthroughs are necessary.

Aerodynamic Environment

The selection of blade parameters was guided by the following basic ground rules, based upon the requirement that emphasis should be placed upon the use of existing components, and the corollary that the objectives should be accomplished with minor state-of-the-art changes.

1. A cut-down blade using the 0012 section with existing linear blade twist was initially considered.

2. Although departures were later made from this concept, the following parameters were retained:

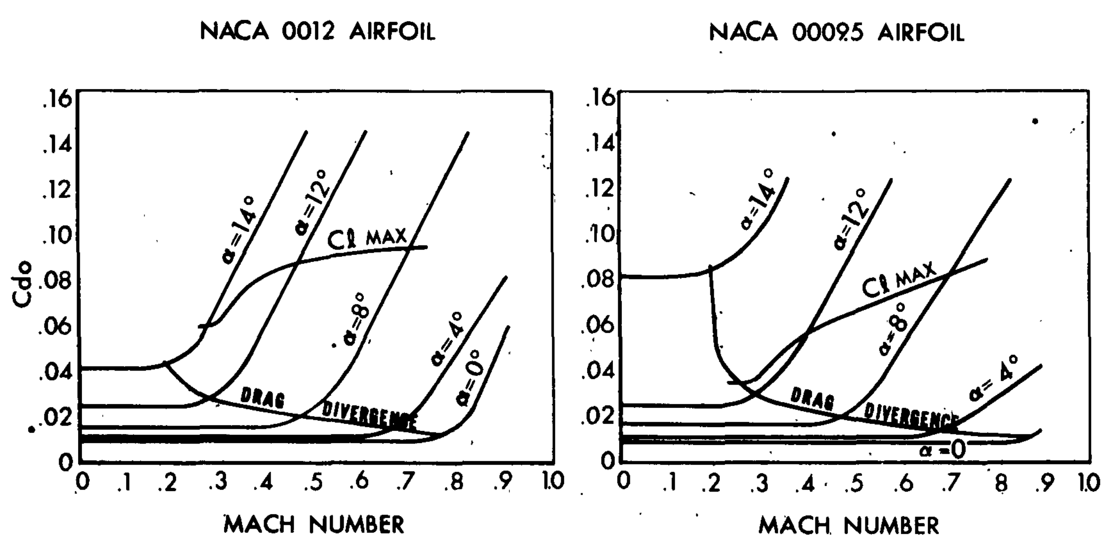
a. Constant chord (no taper, a tooling advantage).

b. Linear blade twist.

c. Conventional symmetrical airfoil sections in the 4-digit family, unless clearly indicated as inapplicable.

d. Constant thickness ratio with radius except for fairing at the root end appropriate to the special aerodynamic environment in that area.

Cdo vs MACH NUMBER FOR CONSTANT ANGLE OF ATTACK



One of the major aspects of the rotor performance is the nature of the airfoil section in terms of minimum drag coefficient at low Mach number, the drag divergence Mach number, the maximum lift coefficient at the moderate Mach numbers of the retreating blade and the drag rise as stall is approached.

The drag coefficients of the 0012 and the 0009.5 airfoils are presented above as they vary with angle of attack and Mach number. The 0012 airfoil data is synthesized from NASA rotor whirl tower data. The 0009.5 airfoil characteristics were derived from considerations of a number of related tests. The details of these aspects are discussed in the "Design Analysis Report," R-234, Reference 1.

The 0012 section was considered first, consistent with the original intention of using a cut-down existing YHC-1B blade which incorporated that section. The 0009.5 airfoil was subsequently employed when design studies indicated the need for a lower thickness ratio to obtain acceptable blade dynamic characteristics As will be shown, the use of that section also provided better matching to the aerodynamic environment. As the graph indicates, the 0009.5 has superior drag characteristics at high Mach number, a lower minimum drag coefficient at low Mach number, but a lower maximum lift coefficient in the low Mach number range.

Polar plots showing the variation of non-dimensional blade loading, $\frac{\partial C_P/\sigma}{\partial X}$; non-dimensional profile power $\frac{\partial C_{P_0}/\sigma}{\partial X}$, angle of attack and the stall and drag divergence boundaries over the rotor azimuth are shown on the following pages for the 0012 airfoil section two advancing tip Mach numbers and constant tip speed ratio and blade twist. Similar plots for the 0009.5 airfoil are shown on a transparent overlay to facilitate comparison.

Each of the four sets of data represents an optimum lift-to-drag ratio situation which is achieved by proper choice of collective pitch. A typical value of 9 degrees of blade twist, representative of current practice, is used for illustration. The effect of twist is shown in more detail in Reference 1.

The advancing side drag divergence boundary for the 0012 case is seen to enlarge with increasing tip Mach number. This is the primary cause of the deterioration of rotor lift to drag ratio from 8.93 to 6.41. The 0009.5 case exhibits this same boundary change. It is, however, not nearly as severe at either tip Mach number as the same effect with the 0012. Consequently, the lift-to-drag ratio with the thinner airfoil is higher and does not fall so drastically as advancing tip Mach number increases. It is, therefore, a better choice for high speed applications.

The other two boundaries, stall and retreating side compressibility, are seen to be relatively insensitive to either Mach number change or variation in airfoil section. This is not really surprising since, for a given Mach number, the lift-to-drag ratio always tends to maximize at a blade pitch associated with a small amount of stall on the retreating side.

The angle of attack variations for the four cases are very similar except that the 0009.5 cases show lower angles of attack on the retreating side consistent with the lower maximum lift coefficient of that airfoil. All four cases indicate negative angles of attack near the tip of the advancing side.

The negative angle of attack area is reflected in the blade loading plots. The negative angles are largely a consequence of a negative increment due to blade flapping. The blade on the advancing side generally rises, causing a negative contribution to the local angles of attack. Areas of positive lift appear to maximize along the fore and aft axis of the rotor. These comments apply to all four cases of optimum rotors.

Examination of the profile power plots provides meaningful insight into the effects of operational high tip Mach numbers and the relative applicability of the two airfoils under consideration. The 0012 case optimized for maximum rotor L/D_E at a tip Mach number of .85. It can be seen that the maximum profile power is consumed on the advancing side due to compressibility drag and high dynamic pressures. This reaches a peak near the outer edge of the disc. At a Mach number of .9 this effect is aggravated noticeably, which explains the sharp drop-off in lift-to-drag ratio.

There is evidently a second but less significant area of a high profile power from $\psi = 300^\circ$ to $\psi = 20^\circ$ associated with high angles of attack and moderately high Mach numbers. The expanse of this effect is nearly equal for both airfoils at either advancing tip Mach number.

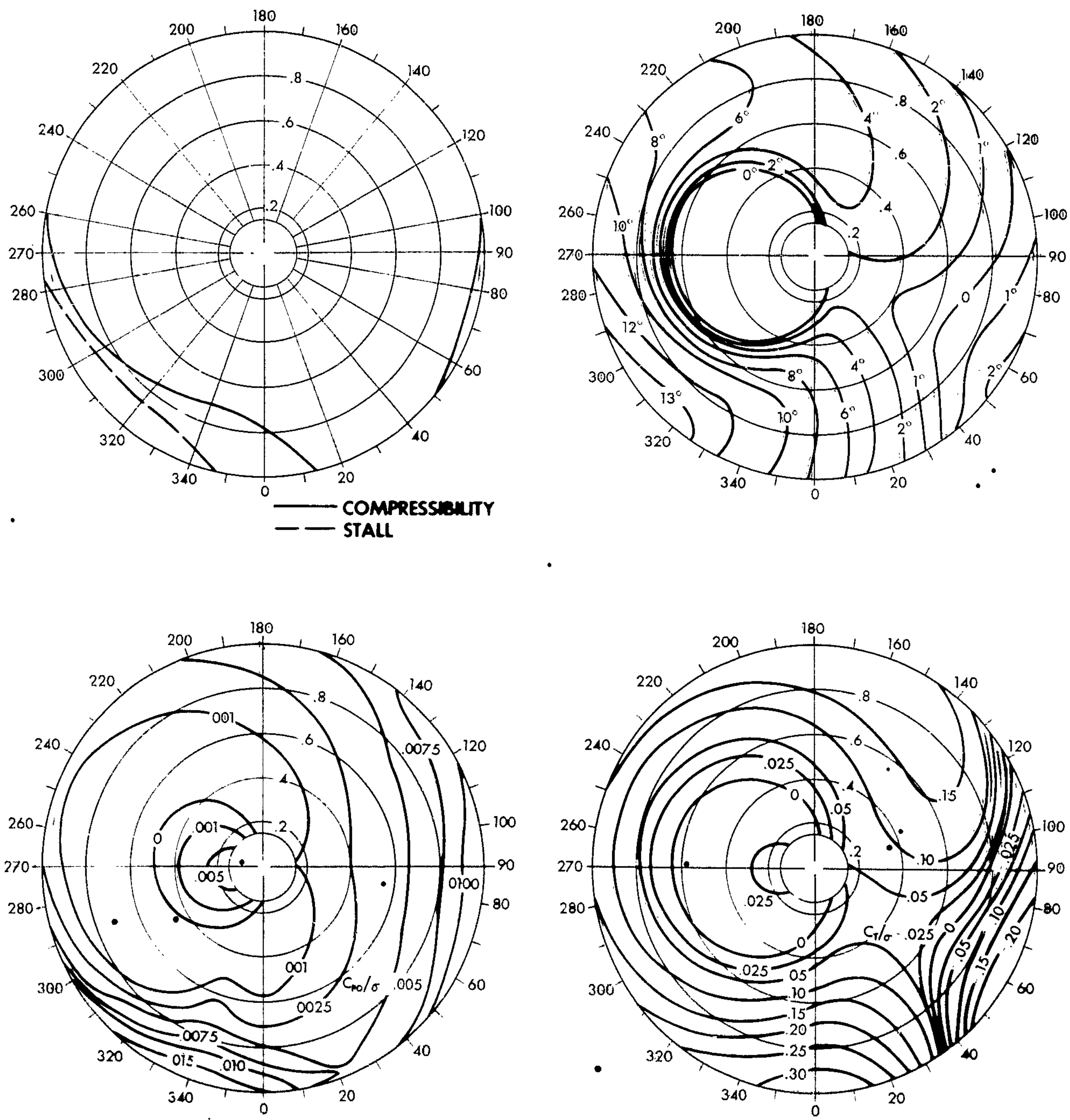
The area of high profile power near the advancing tip of the 0012 cases is due to the relatively low drag divergence Mach number of the 0012 section. It is therefore suggested that the primary means for improvement would be a reduction in airfoil thickness ratio to obtain a better drag characteristic at high Mach number. This is borne out by the presentation of the 0009.5 cases which show marked reduction in the severity of this area of high power consumption. The extent of the area is less and the values of power are lower. The efficiency of the 0009.5 configuration is illustrated by the higher lift-to-drag ratios. Even at a tip Mach number of .9, the L/D_E is higher than that of the 0012 case at a Mach number of .85.

The 0009.5 section was also favored on the basis of dynamic considerations. Thus, this thinner section appears to be a valid solution to the rotor requirements.

NACA 00095

$\mu = 0.45$ $\lambda = -0.15$ $M_t = 0.85$ $\theta_t = -9^\circ$ $\theta_c = 19.07^\circ$ $\sigma = 0.10$

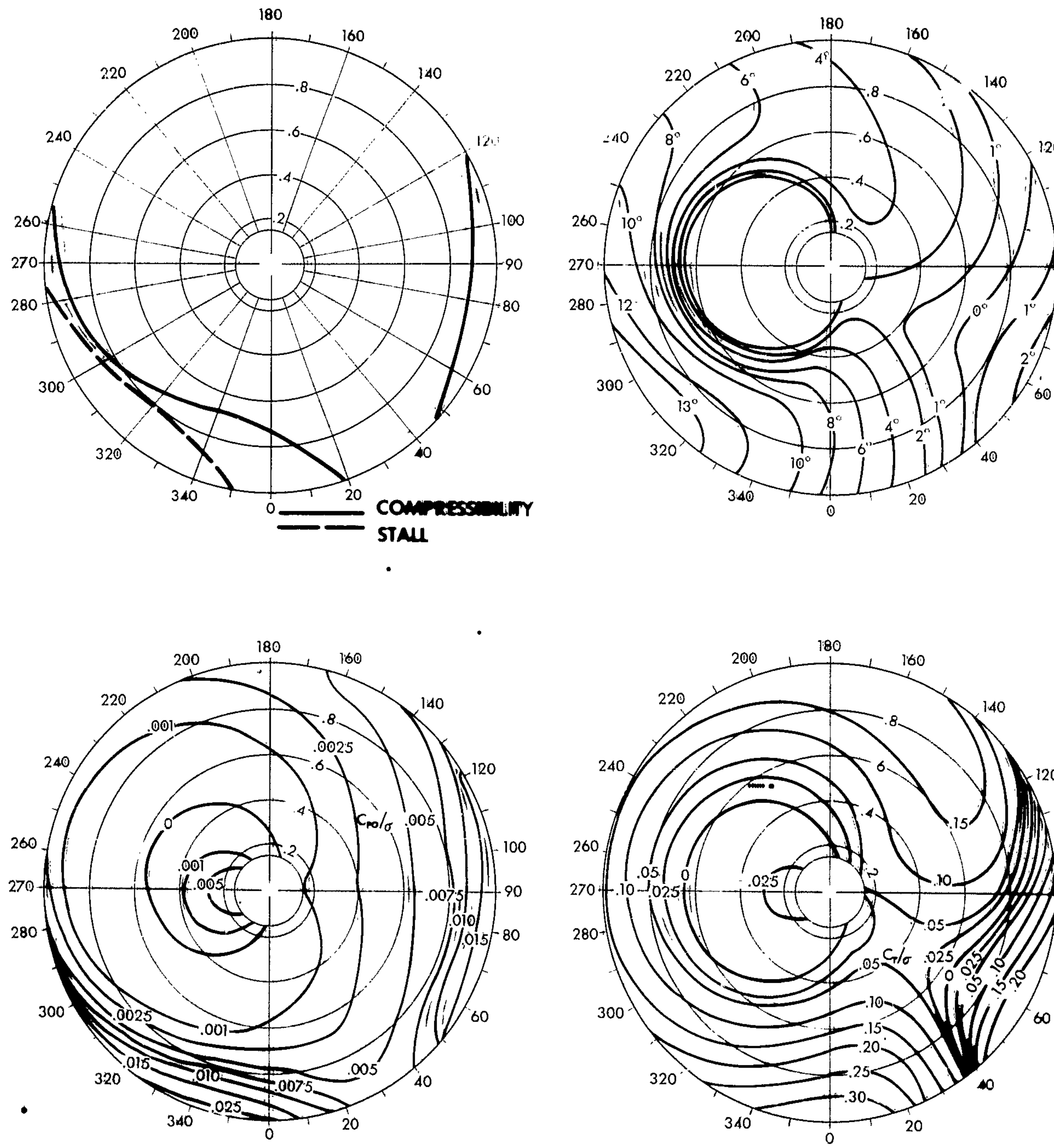
$L/D_E = 11.13$ $C'_T/\sigma = 0.0507$ $X/L = 0.1284$



NACA 00095

$\mu = 0.45$ $\lambda = -0.15$ $M_t = 0.90$ $\theta_t = -9°$ $\theta_o = 19.03°$ $\sigma = 0.10$

$L/D_E = 10.30$ $C'_T/\sigma = 0.0506$ $X/L = 0.1276$

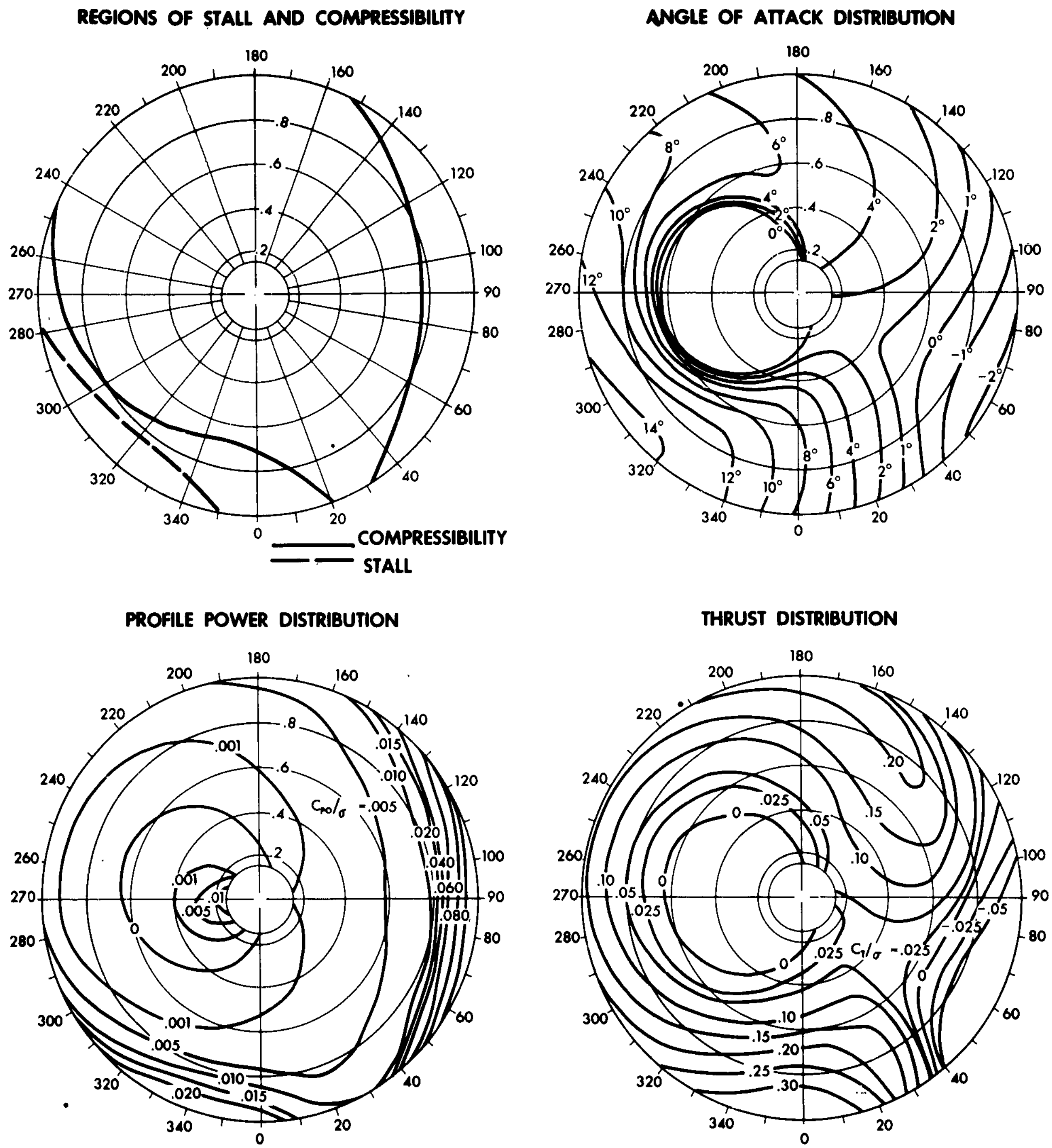


ROTOR AERODYNAMIC ENVIRONMENT:

NACA 0012

$\mu = 0.45 \quad \lambda = -0.15 \quad M_t = 0.90 \quad \theta_t = -9° \quad \theta_0 = 19.230° \quad \sigma = 0.10$

$L/D_E = 6.40 \quad C'_T/\sigma = 0.0564 \quad X/L = 0.1058$



Comparative Tests of Production Blade Specimens

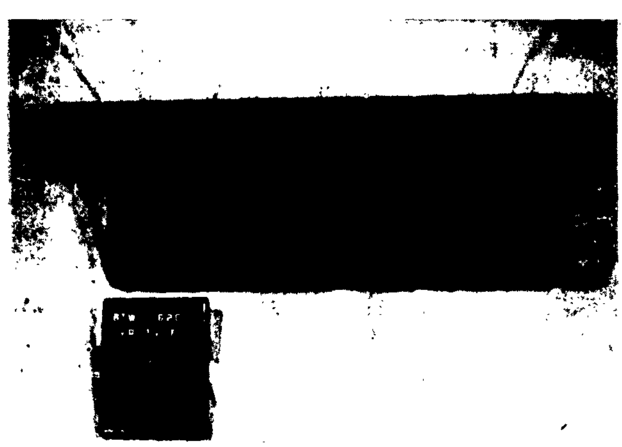
The purpose of these tests was to obtain comparisons of the aerodynamic characteristics of production blades versus ideally contoured smooth specimens. In December 1960, Vertol tested two ideal and six production three-dimensional samples. All specimens had the same aspect ratio (geometric AR = 2.5; reflection plane AR = 5.0). Tests were conducted up to a Mach No. of .9 through the complete angle of attack range at the Boeing Transonic Tunnel.

SPECIMEN IDENTIFICATION

B_1 SMOOTH IDEAL BLADE NACA0012 AIRFOIL
*B_2 SMOOTH IDEAL BLADE NACA0012 AIRFOIL
*B_4 H-21 WOOD BLADE NACA 0015 AIRFOIL
*B_5 MODEL 44 METAL BLADE 0012 AIRFOIL
*B_6 MODEL 44 METAL BLADE, EROSION STRIP ON NACA 0012 AIRFOIL
*B_7 MODEL 107 II BLADE, NACA 0012 AIRFOIL
*B_8 HC-1B BLADE, ANTI-ICING CAP ON NACA AIRFOIL 0012

*PLUS TRAILING EDGE EXTENSION

The accompanying table lists the pertinent characteristics of the various specimens tested. The photographs show a typical blade specimen and installation in the Boeing Transonic Tunnel.



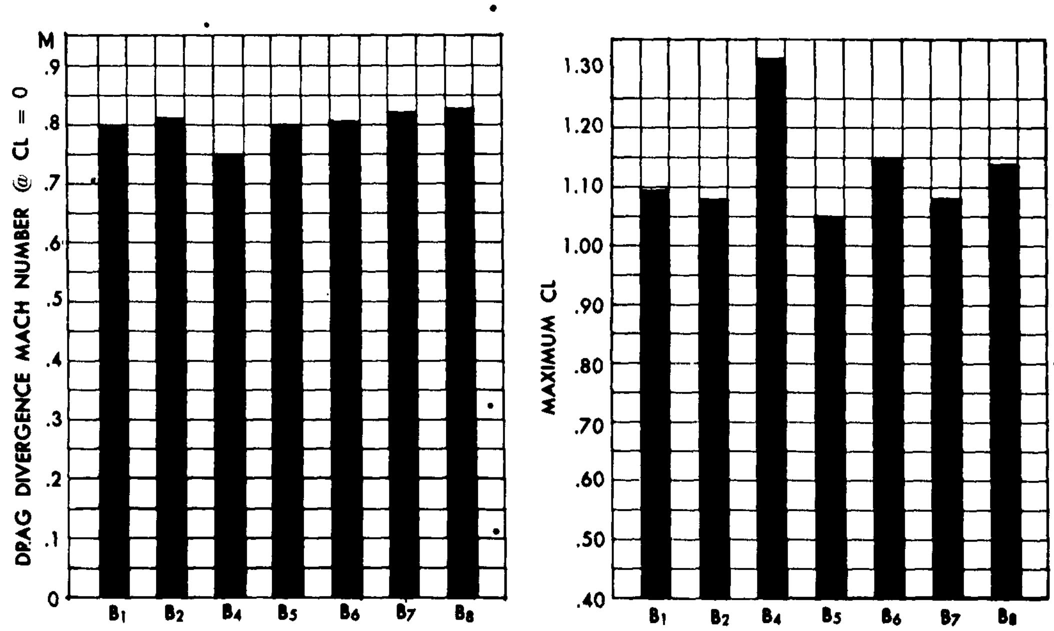
Results of Comparative Airfoil Tests

Lift, drag and pitching moment were measured for each blade specimen using the standard wind tunnel balance system. The intent of the test was to establish a comparison of the aerodynamic characteristics on an incremental rather than absolute basis. The practical specimens have C_D min values from .0005 to .0011 higher than that for the corresponding ideal specimen.

The C_L max data are shown in the accompanying figure. Comparing the ideal specimens B1 and B2 first, a slight advantage (ΔC_L = .015) is shown for the specimen without the trailing edge extension. The effective thickness of the ideal specimen with trailing edge extension is 11% and the slight drop in C_L max is expected. B4, approximately 15% thick, shows the highest $C_L$max. B5 and B7 show slight decreases when compared to B2. In general, the C_L max data is reasonable and production blades do not indicate large losses when compared to ideal specimens.

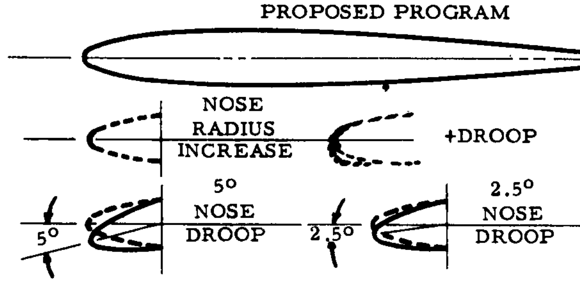
Drag divergence Mach number at $C_L = 0$ is approximately .8 for all specimens tested except B4. For B4, the 15% thick blade, drag divergence occurs at ΔM = .05 earlier. Vertol production blades have acceptable aerodynamic characteristics.

A further wind tunnel investigation to obtain specific rotor airfoil data for the high performance helicopter is scheduled at the Boeing Transonic Tunnel in late February 1961. The variations of the 0009.5 airfoil to be tested are shown in the accompanying table. The purpose of this



program is to obtain substantiation of the airfoil characteristics presented on page 14 of this section and to achieve improvements in $C_L max$ at little or no loss in the desirable Mach divergence characteristics of the 0009.5 section.

PROPOSED PROGRAM

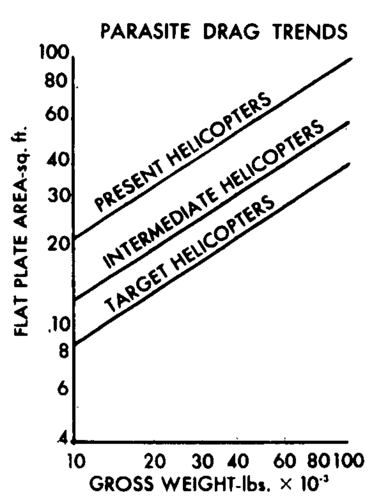


DAGGER TEST SPECIMENS
WITH TRAILING EDGE EXTENSION

1	NACA 0009.5	
2	NACA 0009.5	NOSE RADIUS INCREASE
3	NACA 0009.5	2 1/2° NOSE DROOP
4	NACA 0009.5	5° NOSE DROOP
5	NACA 0012	REFERENCE BLADE
6	H-21 BLADE WITH "DROOP SNOOT"	

Parasite Drag Reduction

Aerodynamic cleanliness or reduction in parasite drag is necessary to achieve extended ferry range and high speed efficiently. The trend curve of flat plate area versus gross weight indicates present, intermediate and future goals. The high drag associated with present day helicopters is due primarily to development emphasis placed in the areas of improved reliability, simplification of maintenance and improved flying qualities. The means of achieving the drag values of the "intermediate" class are available today and have been demonstrated through extensive wind tunnel testing. Programs are in progress to achieve the goals of the future helicopter, and results of these efforts should be forthcoming shortly.

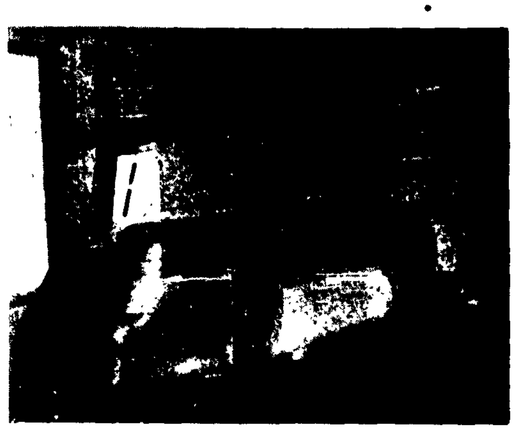


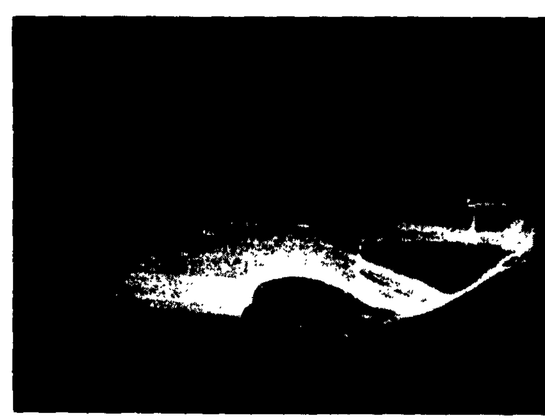
The table below presents a drag breakdown of the Boeing-Vertol 107. Data presented in the first column have been corroborated by flight test results. The next column depicts the drag of a cleaned-up version based upon completed wind tunnel test programs. The final column represents design values that are believed achievable within the near future.

BOEING-VERTOL 107 SERIES			
	V-107-II	ADV. 107	FUTURE
FUSELAGE	10.6	9.7	6.2
WING STUBS	2.8	2.8	1.1
ROTOR HUBS	8.5	5.0	4.0
LANDING GEAR	4.4	0	0
AIR INLETS	1.5	1.5	.6
PROTUBERANCES	1.0	.5	.5
ROUGHNESS	1.4	1.0	.6
TOTAL (SQ. FT.)	30.2	20.5	13.0

Boeing-Vertol 107 Drag Reduction Program

The 107 helicopter series has been developed through a continuing program of wind tunnel and flight testing. Original testing of the 107 prototype during 1957 was continued on the YHC-1A during 1959 and 1960. The present contract led to further testing with an eighth scale static model to establish configuration changes which would ensure significant performance increases.

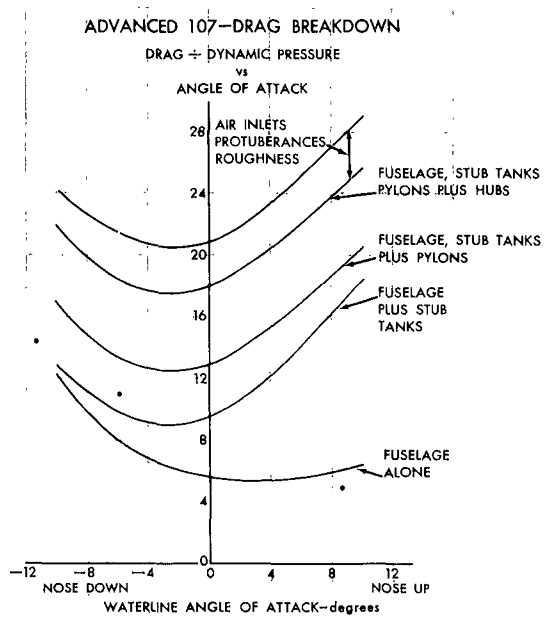




Flow studies (using fluorescent oil, tufts, and surface pressures) were used throughout the program to delineate areas of separation and enable concentrated efforts to reduce their effects. Quantitative data from force and moment measurements completed the program.

In-flight tuft and pressure studies have substantiated and supplemented the wind tunnel efforts throughout the development of Boeing-Vertol helicopters. A typical in-flight tuft study of the 107 prototype is shown below.

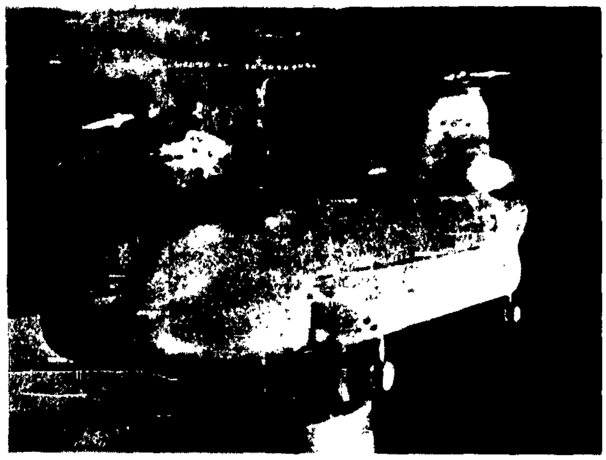
Through continuous and complete wind tunnel and flight test research, the future goals for drag reduction will be realized.



Chinook Drag Reduction Program

The Chinook design effort was preceded by extensive wind tunnel testing. An eighth-scale model was fabricated and tested at the University of Maryland. Vertol has conducted these wind tunnel efforts to improve both the drag and stability characteristics of the basic Chinook for future product improvement. An extensive program of drag reduction was initiated during the latter part of 1960. These efforts included investigation of the nose enclosure, afterbody, forward and aft pylons and fuel pods. The examination started with the bare fuselage. Once the drag of the fuselage was reduced to pre-determined target values, each additional component was added and investigated in detail. The table

below presents a drag breakdown for the Chinook and follow-on versions similar to the 107 presentation.



CHINOOK SERIES			
	YHC-1B	ADV. YHC-1B	FUTURE
FUSELAGE	7.5	7.0	7.0
AFT. PYLON	2.0	1.1	1.1
FWD. PYLON	1.7	1.0	1.0
PODS	3.0	1.9	1.1
AFT. HUB	7.2	4.6	3.0
FWD. HUB	6.9	4.4	3.0
NACELLES	1.9	1.9	.8
LANDING GEAR	7.9	0	0
PROTUBERANCES	1.9	.9	.2
AIR INLETS	1.2	1.2	.3
ROUGHNESS	2.0	1.0	.5
TOTAL (SQ. FT.)	42.2	25.0	18.0

A brief summary of the Chinook wind tunnel results are presented below. More detailed analysis may be found in References 2 and 3. The afterbody was subjected to extensive testing to reduce drag commensurate with minimum length and rear loading capability. Various flow visualization techniques were employed in this investigation. The table below presents drag and lift data for various afterbody shapes on the Chinook fuselage.

In the investigation of hub-pylon drag, a powered hub was employed to determine interference effects. To separate these effects the hub was suspended from the tunnel ceiling at various distances from the model. Total drag was measured with the hub installed on the model.

ADVANCED CHINOOK WIND TUNNEL TEST PROGRAM AFTERBODY COMPARISON -- CHINOOK NOSE INSTALLED

FRONTAL AREA = 70ft.	Contract. Ratio l/d	Camber Ratio h/l	MINIMUM DRAG α Min. Drag	MINIMUM DRAG fe @ α Min. Drag	MINIMUM DRAG C_D @ α Min. Drag	fe / L/q α = -5°	fe / L/q α = o	fe / L/q α = +5°
SHORT CHINOOK	1.0	.27	+5°	7.9	.113	14.1 / -23.7	12.3 / -14.7	7.9 / 5.0
STANDARD CHINOOK	1.5	.27	+3°	6.5	.093	10.1 / -18.6	7.5 / -7.7	6.8 / 4.4
LONG CHINOOK	2.25	.27	+3°	6.1	.087	10.8 / -19.2	7.0 / -7.1	6.5 / 1.2
SHORT SYM.	1.0	0	0	8.1	.116	8.1 / -5.2	8.1 / -1.3	8.7 / 11.4
STD SYMMETRICAL	1.5	0	0	5.75	.082	6.3 / -7.1	5.75 / 1.3	7.4 / 8.3
LONG SYMMETRICAL	2.25	0	0	5.1	.073	6.0 / -7.1	5.1 / -0.6	6.4 / 8.9
STANDARD TEARDROP	1.5	0	-2°	5.75	.082	6.5 / -3.8	6.1 / 1.9	6.6 / 7.7

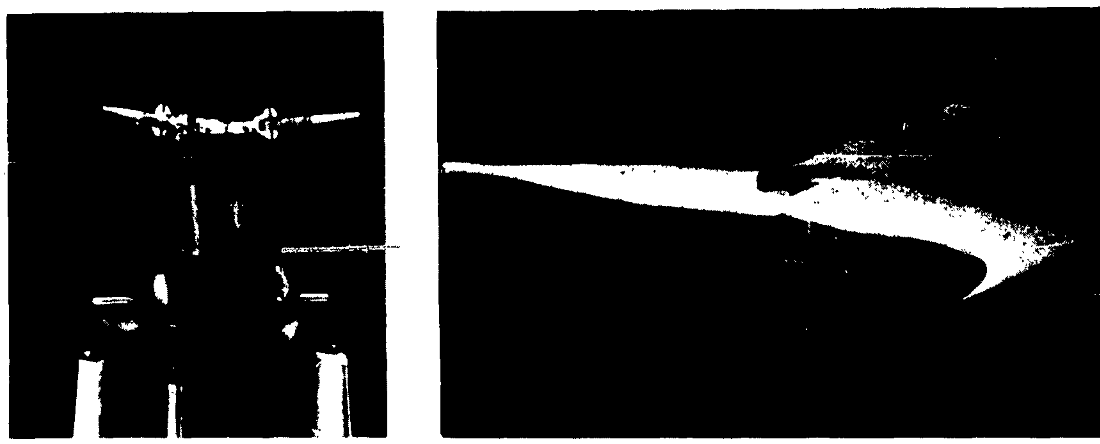
Hub Fairing Studies

Vertol has recently been involved in a comprehensive investigation of rotor hub drag and development of fairings for reduction of hub drag. The ultimate goal of this program is to eliminate hub-pylon interference drag and to reduce hub pressure drag to an absolute minimum.

Tests of rotating and stationary hubs have been performed on small scale models of both tandem and single rotor helicopters; but in order to accurately separate the component source of hub drag, a large scale rotating model incorporating both cyclic and collective pitch and removable components is necessary.

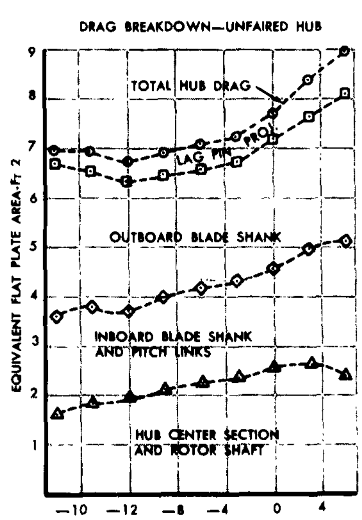
A 1/3 scale powered model of the YHC-1B (Chinook) hub and pylon was designed and fabricated for wind tunnel testing. The model incorporated cyclic and collective pitch provisions and an integral hub balance sys-

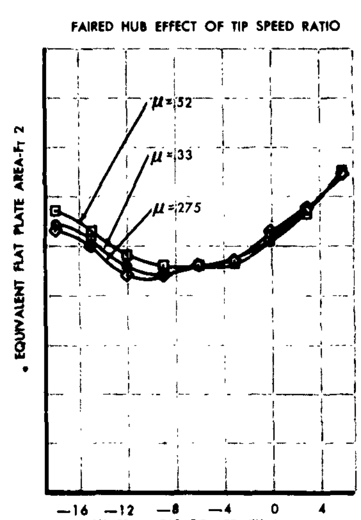
tem in order to distinguish between hub drag and hub-pylon interference drag. The objective of the production hub test was to determine the magnitude of drag originating from the individual hub components so as to provide a rational basis for estimation of various hub configrations and a rational basis for hub fairing development.

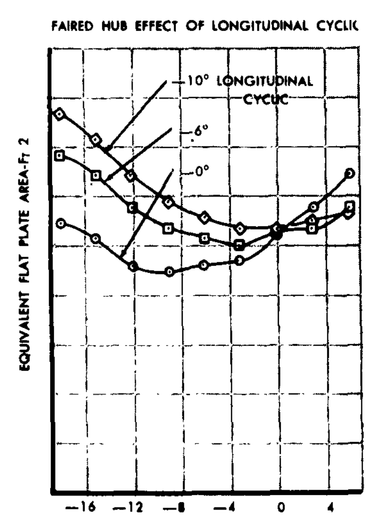


Hub Fairing Studies

The magnitude of drag, indicated by the tests for the complete hub, falls essentially in line with projected values for other hub types. The detailed breakdown of component drag, obtained by progressively removing items from the model, is shown below. Examination of the component drag values, along with pertinent areas and effective drag coefficients, should indicate the potential areas and improvements to be realized.







A second objective of the subject test program was to evaluate the effectiveness of individual blade shank fairings as a means of hub drag reduction. Theoretical analysis of fairings for this hub had indicated that, for the large variations of pitch, flapping and lag angles incurred during the flight envelope of a modern high-speed helicopter, the individual blade shank fairing will provide the maximum relief to rotor hub drag. Further study revealed that reverse flow on the retreating blade root dictated an elliptical fairing with incidence and twist optimized on the basis of minimum average drag of the advancing and retreating blades. A fairing based upon these design considerations was fabricated and tested during the program. Tests were performed to investigate effects of Reynolds Number, tip speed ratio, cyclic pitch, and inflow angle on lift, drag and shaft power required. Some of these effects are shown in the adjoining figures. Variations of longitudinal cyclic pitch exhibited a very significant effect on both drag and power. Tip speed ratio variation also had a rather definite influence on drag. This would be expected since both these parameters enter into the relations to define optimum fairing incidence angle.

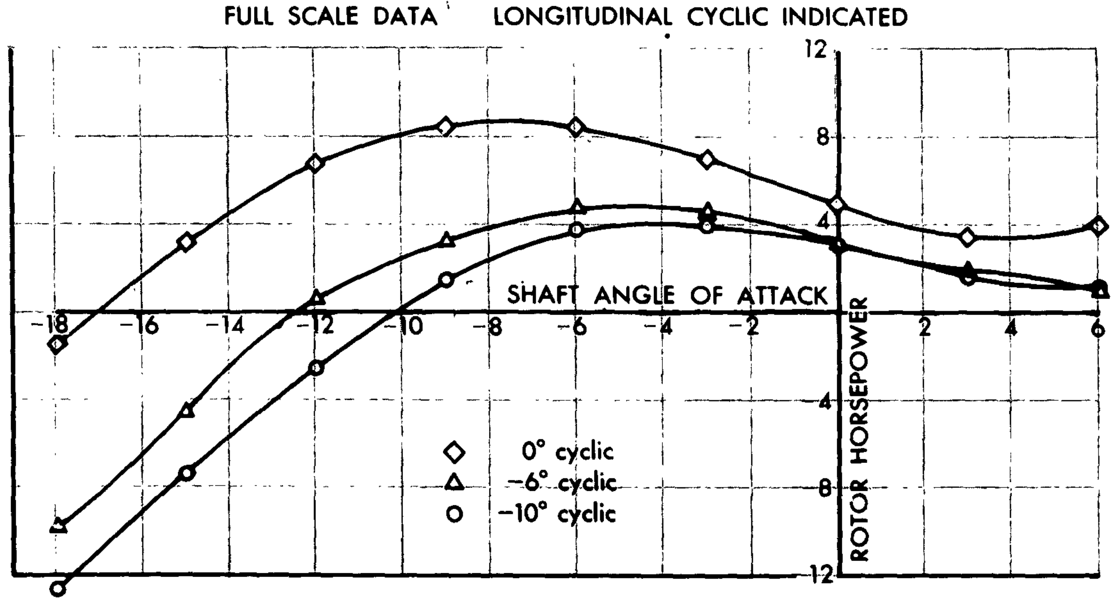
Future development programs for the fairings are to include investigation of larger thickness ratio fairings (present fairing models are 25% t/c) and optimization of incidence angle for specific cruise flight conditions. The present fairing model yielded a 36% reduction in hub drag; however the initial goal of 50% reduction is considered attainable.

YHC-1B ⅓ SCALE FAIRED POWERED HUB

ROTOR HORSEPOWER VS SHAFT ANGLE OF ATTACK

V_T = 665 fps V_0 = 220 fps = 130 kts μ = .33

FULL SCALE DATA   LONGITUDINAL CYCLIC INDICATED



Stability and Control

The trim characteristics of the advanced 107 are very similar to those of the Boeing-Vertol 107-II. The use of a modified automatic differential collective pitch schedule ensures a smaller total longitudinal trim change with airspeed on the advanced 107, even though its absolute speed capability exceeds that of the 107-II. Lateral directional trim of the two aircraft should be almost identical. The cambered aft pylon supplies directional trim moments which vary with airspeed, eliminating the need for pilot trim inputs with change in airspeeds.

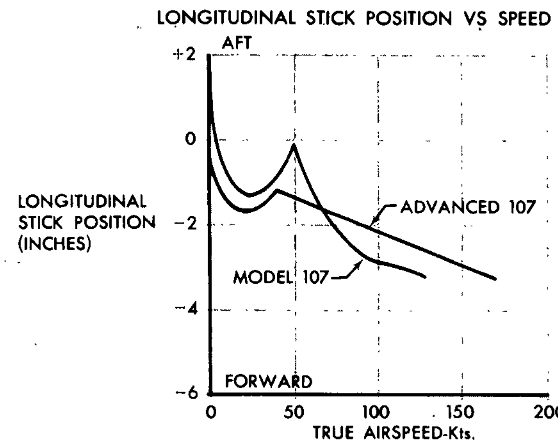
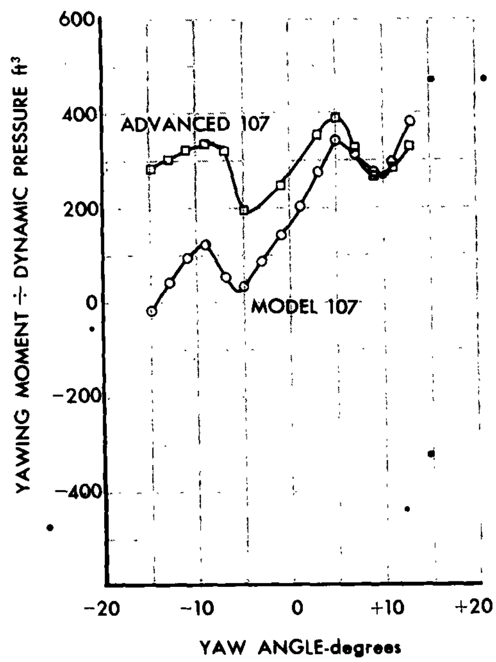


TABLE I - PHYSICAL DATA FOR THE MODEL YHC-1A AND THE MODEL 107 SERIES			
CONTROL KINEMATICS	YHC-1A	107-II	ADV 107-II
(a) Collective Pitch			
Collective Pitch Lever-Travel	12.00 in.	12.00 in.	12.30 in.
Collective Pitch Change @ 0.75R	1→17 deg.	1→17 deg.	1→18 deg.
(b) Longitudinal Control			
Longitudinal Stick Travel	± 5.00 in.	± 6.00 in.	± 5.80 in.
D.C.P. Blade Travel due to Stick	± 3.00 deg.	± 4.00 deg.	± 4.00 deg.
D.C.P. Blade Travel due to "q" Sensor		± 1.91 deg.	± 3.00 deg.
Cyclic due to "q" Sensor Fwd.	- 2.0 deg. (fixed)	- 2.34 deg. (fixed)	0↔-10.7 deg.
Cyclic due to "q" Sensor Aft.	+.5→ -8.5 deg.	+.5→ -7.0 deg.	+.5↔-10.7 deg.
Stick Positioner - Stick Range	± 2.0 in.	± 1.5 in.	± 1.5 in.
Stick Positioner - Blade Travel	± 1.0 deg.	± 1.0 deg.	± 1.0 deg.
(c) Lateral Control			
Lateral Stick Travel	± 3.6 in.	± 3.6 in.	± 3.6 in.
Lateral Cyclic Blade Travel Fwd.	± 7.27 deg.	± 9.0 deg.	± 7.80 deg.
Lateral Cyclic Blade Travel Aft.	± 4.73 deg.	± 7.5 deg.	± 7.80 deg.
(d) Directional Control			
Rudder Pedal Travel	± 2.3 in.	± 2.3 in.	± 2.3 in.
Lateral Cyclic Blade Travel Fwd.	± 7.13 deg.	± 9.5 deg.	± 9.85 deg.
Lateral Cyclic Blade Travel Aft.	± 7.13 deg.	± 9.5 deg.	± 9.85 deg.

The increased speed capability of the advanced 107 necessitated some changes in control system throws, primarily in the collective pitch. Increased collective pitch is required to overcome the additional inflow present due to the increased speed capability. Control system characteristics of these models of the 107 series are presented in the table at the bottom of the opposite page.

A marked increase in directional stability was achieved through development of the afterbody and aft pylon contours. The directional instability at small sideslip angles exhibted by the 107-II is compensated by the SAS through use of a control system extensible link which responds to a sideslip signal. The mild instability of the advanced 107 will be handled in an identical manner.



The Stability Augmentation System (SAS) installed in the advanced 107 is similar to the system operationally proven in the Boeing-Vertol 44, 107 prototype, Army YHC-1A, and planned for the Army YHC-1B. As such, it will ensure the same "fixed-wing" flying qualities, such as short term hands-off flight and coordinated stick turns, to this aircraft that it does to those now flying.

The complete reliability required for IFR flight capability is attained through the twin design approach paths of simplicity and duplication. A SAS contains only about 1/4 the number of critical components and weighs only about 1/3 as much as a standard helicopter ASE. Therefore,

it becomes feasible to install two complete systems, each of which operates from separate electrical and hydraulic power supplies. Both systems normally operate together, but in the event of any failure, the remaining system takes over the entire stabilization task.

Each of the three SAS axes consists of a rate gyro, an electric signal amplifier, and a hydraulic actuator which responds to electrical signals. The yaw axis also contains a sideslip sensor to improve turn coordination. Actuators are of the series type which prevents any signals from being felt at the pilot controls. They also have limited authority, so that the pilot is able to retain full control in the event of any failure.

All critical components are contained in a single, easily replaceable box, with a built-in "press-to-test" button and indicator.

Conclusions

The aerodynamics of the high performance helicopter, as related to extended range and speed, have been reviewed. In particular, a thorough knowledge of the aerodynamic environment in which the rotor must operate has received particular attention. The results of these analytical investigations indicate that efforts should be made in obtaining an airfoil section with improved Mach divergence characteristics.

Reduction of parasite drag is vital to achieve the performance requirements. During this study period, extensive wind tunnel tests have been conducted for both the advanced 107 and advanced YHC-1B configurations. Substantial reduction of drag is possible with minor changes to either aircraft.

The results of these investigations, both analytical and test, indicate that the immediate performance requirements of 1600 n.mi. ferry range and 200 mph cruise speed can be attained with minor changes to either the Boeing-Vertol 107 or YHC-1B helicopter.

DESIGN CONSIDERATIONS

Introduction

The basic concept of this design study has been to obtain high performance using the maximum possible proportion of existing components. Emphasis was placed on production and operational suitability. These considerations contributed to the initial decision to modify the Boeing-Vertol 107 helicopter with a minimum of additional expense in the production of new components.

The experience gained in developing solutions for the advanced 107 is applicable to the YHC-1B and permits a confident determination of the necessary changes to obtain an advanced YHC-1B.

Advanced Boeing-Vertol 107 Configuration Study

The configuration finally selected for its high performance potential is the advanced 107 shown in three-view drawing number SK10315.

Areas of change compared to the Boeing-Vertol 107-II may be summarized as follows:

Major Changes:

1. Rotor blades
2. Rotor hub
3. Rotor controls
4. Rear fuselage
5. Landing gear retraction

Minor Changes:

1. Flight controls
2. Miscellaneous fuselage areas for flushing and fairing

These changes are described in more detail in paragraphs 1 through 5. Corresponding changes to utilize the YHC-1B instead of the 107 are described on page 40.

1. Rotor Blades

The rotor blade proposed for the advanced 107 helicopter is the result of a rigorous design effort to achieve greater rotor solidity without accepting an excessive weight penalty with its accompanying centrifugal forces, and without sacrificing dynamic acceptability which plays an important role in reducing helicopter vibration level. The design described here is of 25' radius and 23" chord, suitable for the research vehicle originally specified under this contract. The studies have made clear that the narrower chord, larger radius blade now recommended, can be achieved by the same methods.

Initial studies centered around a reduced span version of the NACA 0012 airfoil 23-inch chord YHC-1B Chinook blade, thus taking advantage of existing blade tooling. This blade would have weighed 60 pounds per blade more than the final blade design, plus the addition of 20 or 30 pounds of natural frequency weight to each blade, for a total weight penalty of approximately 500 pounds per helicopter in blade weight alone. This would of course require a larger hub and greater capacity retention system.

Further studies were directed toward reducing weight by modifying the spar on the YHC-1B, still preserving most of the tooling built for this blade. Three such blade configurations were designed and analyzed, resulting in the reduction of blade weight by 50 pounds per blade; however, acceptable dynamic characteristics were not produced. The basic problem lay in the fact that, while mass reductions were possible at the cost of expensive manufacturing methods, the stiffness of the blade could not be reduced in the same ratio, hence the first mode flapwise natural frequency (preferably around 2.5) increased toward 3.0 which is dynamically undesirable.

A YHC-1B blade was analyzed using an aluminum spar. For the same weight, stiffness was again too great because of spar thickness, and both natural frequency and blade stresses were excessively high.

Hopes to salvage most of existing blade tooling were then abandoned, and a change to a thinner airfoil section investigated.

The first such blade configuration, based on a 0009 airfoil, used a 5.1-inch diameter spar. Because of manufacturing limitations, the outboard wall thickness of this blade could not be reduced below .060. The resulting mass-to-stiffness ratio was very low and resulted in a blade which was very limber outboard, causing excessive static droop and subject to centrifugal stiffening due to tip weights, thus producing an unacceptably high rotating natural frequency.

The studies discussed on the preceding page, are summarized briefly in the following table:

Blade Configuration	Weight W/O Nat'l. Freq. Weight	First Flapwise Nat'l Freq.	Comments
Reduced Span YHC-1B	227.0	2.578	Saves existing tooling. Short development time. Costs 500 lbs/ helicopter.
Modified YHC-1B Steel Spar A	187.5	2.685	Use much of existing tooling.
B	179.0	2.665	Requires difficult manufacturing techniques to reduce spar weight.
C	172.0	2.612	Requires excessive weight to reduce nat'l. freq.
Reduced Span YHC-1B Aluminum Spar	159.0	2.629	New spar development. Excessive nat'l. freq. weight required. High spar stresses, poor erosion and corrosion characteristics.
.0009 Airfoil, 5.1 Dia. Steel Spar	170.0	2.558	New spar tube complete blade tooling, long lead time, nat'l freq. too high, requires additional weight.

Proposed Design - The rotor blade design studies just reviewed led to a decision to adapt the Boeing-Vertol spar to the longer-chord 23-inch advanced 107 blade. This permits matching the dynamic characteristics of the advanced 107 blade to the Model II blade presently in production.

The design configuration is as follows:

Blade Weight	168# (does not include 18# of tuning wt. assy. in forward blades)
First flap-wise nat'l. freq.	2.43
Airfoil section	NACA 0009.5
Blade Radius	25 Feet
Blade Chord	21.5" Airfoil + 1.5" Cusp = 23" total
Spar	4340 "Rockrited" single piece steel spar, rolled with same tools as Model II with positions of steps changed
Airfoil, aft of Spar	Fiberglas-reinforced epoxy laminated skins bonded over aluminum ribs, structurally bonded to the heel of the 4340 steel spar to comprise the NACA 0009.5 airfoil

While the actual components are completely new, extensive testing on similar Boeing-Vertol 107-II and YHC-1B blade box construction indicates excellent serviceability.

Balance Provisions	As with Boeing-Vertol 107, blades are made individually interchangeable by means of close manufacturing control and addition of balance weights in the nose of the spar and in the tip.
Root Fitting	The blade is attached to the hub components with a single pin which serves as the lag hinge. The blade is threaded and clamped to a forged 4340 socket through which the vertical pin is secured. This is the same principle used on the YHC-1B.

Natural Frequency Weight	Fixed 10-pound weights are housed within, but isolated from, the forward blade spars at 40% radius as evaluated on Boeing-Vertol 107-II.

The dynamic characteristics of the Advanced 107 blade match those of the Boeing-Vertol 107-II closely.

		Boeing-Vertol 107-II	Advanced 107
$\omega\ 1_f$	First flapwise mode rotating natural frequency	2.49	2.43
$\mu\ 13_f$	Damped amplification factor, first flapwise mode, 3rd harmonic (measure of 3/rev response)	1.812	1.602
$\omega\ 2_f$	Second flapwise mode rotating natural frequency	4.618	4.632
$\mu\ 25_f$	Damped amplification factor, second flapwise mode, 5th harmonic (measure of flapwise moment response)	4.065	3.963
$\omega\ 1_c$	First chordwise mode rotating natural frequency	4.80	4.774
$\mu\ 15_c$	Undamped amplification factor first chordwise mode, 5th harmonic	12.00	10.33

A careful analysis of the effects of forward speed and blade loadings on blade bending moments has been performed. A comparison has been made with calculated loads on Model II blades and the results cross-checked against measured high speed flight loads on the Model II blades. As a result, it has been concluded that this blade can be designed to infinite fatigue life under the most severe unaccelerated flight conditions up to and including 200 mph design maximum speed. Reference 1 presents additional rotor blade design data.

2. Rotor Hub

The rotor hub is basically of the same configuration as the YHC-1B, with the pitch bearings located inboard of the vertical pin.

The hub design was selected primarily from aerodynamic considerations, giving the smallest possible hub radius and a minimum total frontal area. Studies conducted at the time of the YHC-1B detail design phase also showed this type of hub to be the lightest and to result in a minimum of kinematic errors.

In the interest of further shortening the hub, the tension-torsion straps are of the wire ply type which are now under development at Vertol. This results in approximately 3 in. reduction in the radius from the center of rotation to the vertical pin.

All hub components are new except for the horizontal pin bearings which are identical to the Boeing-Vertol 107-II, and the lag damper which is identical to the YHC-1B except for its end fittings.

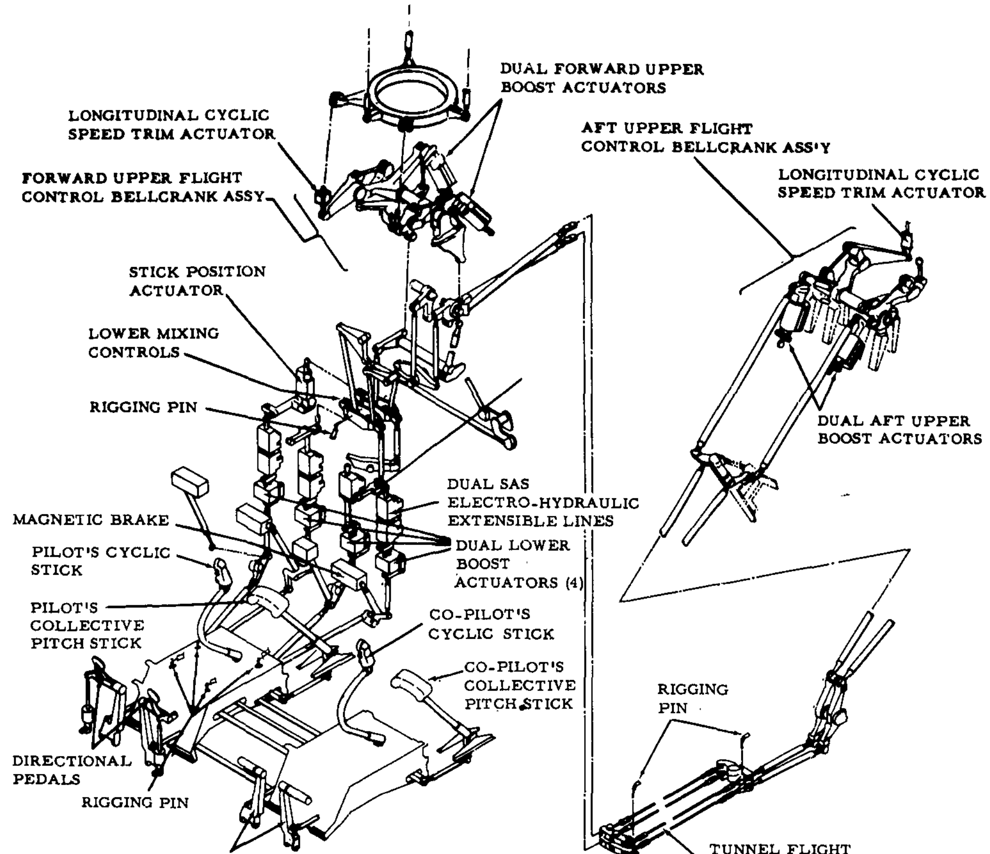
Fabroid is used for vertical pin bearings in accordance with Vertol's latest developments, to minimize vertical pin height and elminate the necessity for lubrication. The pitch arm has been shortened somewhat compared to the 107 in order to help provide the increased control travels required.

3. Control System

a. Rotor Controls - The control system from the swashplate to the blades is essentially new. The higher cruise speed and wider blade chord of this helicopter result in increased control loads which require strengthening and stiffening of the rotor control system as compared to the Vertol 107. However, in this new design, the principles of the Vertol 107 rotor control system have been retained and it has been possible, also, to retain the same ball tracks on the swashplate bearing and the same bolt hole location for the attachment for the swashplate rings. By this means, all major tooling for the Vertol 107 rotor control system can still be used.

b. Flight Control System - The increased control loads in the high performance helicopter necessitate changes in the bell cranks at the rotor end of the control system to increase their strength and stiffness. This is achieved mainly by making them out of steel. The system pressure in the control boost is increased from 1500 to 2000 psi in order to deal with the higher control loads. Ample strength is available in the existing actuators for the increased system pressure.

Minor bell crank changes are made in the lower system to adjust the control travels to the required values.



CONTROLS

4. Alighting Gear

The wheels, tires and oleos of the 107 are retained on the high speed version but their attachments are modified to permit retraction.

On the main gear, this requires provision for new attachments to the stub wing and the installation of an electrical actuator to permit forward retraction of the gear. The fuel tank is modified to provide retraction space, and hinged doors close all gaps when the gear is in the retracted position. The system is arranged so that all sequencing is mechanical.

With regard to the nose gear, a different mounting has been incorporated in order to permit swiveling as required, with an electrical actuator for rearward retraction. Cutouts and doors are provided in the fuselage to accommodate and enclose the retracted gear.

5. Fuselage

The basic fuselage cross section of the Boeing-Vertol 107 has been retained, together with the rear ramp loading feature.

In order to save drag, the lines of the rear portion of the fuselage have been refaired. This requires a new rear fuselage structure. At the same time that the rear fuselage is refaired, the pylon is moved aft by 15" to permit the installation of longer blades.

Minor changes are made in the cockpit enclosure to provide flush windows and increase strength in the plexiglass areas, compatible with the increase in forward speed. Miscellaneous minor fairing will also be used in areas such as heater intake, vents, drains, etc., and minor strengthening in some cowling areas to sustain the increased air loads.

Advanced YHC-1B Design Details

Practically all the design studies were directed toward the conversion of the 107 to the high performance configuration. Design layouts of a similar nature for the YHC-1B were not undertaken in any great detail. The experience gained, however, in developing solutions for the advanced 107 is applicable to the YHC-1B and permits a confident determination of the necessary changes to that aircraft to attain the same objectives. A brief description of the changes required from the YHC-1B to the high performance version follows:

1. Rotor Blades

No design studies were undertaken with regard to an advanced YHC-1B blade due to the late decision to consider that aircraft for a high performance configuration. It can be stated, however, that the results of the 107 study to obtain a blade suitable for 200 mph flight are generally applicable and that a satisfactory YHC-1B blade design could be developed using the same principles.

2. Rotor Hub

The rotor hub is basically of the same configuration as the YHC-1B, with the pitch bearings located inboard of the vertical pin. In order to minimize frontal area, however, the actual parts are redesigned to incorporate wire ply tension-torsion straps and Fabroid vertical pin bearings. The existing YHC-1B horizontal pin bearings and lag damper are retained.

3. Control System

a. Rotor Controls - The control system from the swashplate to the blades is essentially new. The higher cruise speed and wider blade

chord of this helicopter result in increased control loads which require strengthening and stiffening of the rotor control system as compared to the YHC-1B. However, in this new design, the principles of the YHC-1B rotor control system have been retained and it has been possible also to retain the same ball tracks on the swashplate bearing and the same bolt hole location with the attachment for the swashplate rings. By this means, the major tooling for the advanced YHC-1B rotor control system can still be used.

b. Flight Control System - It is anticipated that the control loads, even at higher speed and with greater solidity will be within the capacity of the existing boost system. The only changes in the lower control system will, therefore, be minor bell crank changes to adjust control travels to the required values.

4. Landing Gear

The wheels, tires and oleos of the YHC-1B are retained on the high speed version but their attachments are modified to permit retraction.

On both the main and nose gears, this requires provision of new attachments to the fuel blister or fuselage, the provision of a hydraulic actuator, and modifications to the rear and forward fairings of the blisters to accommodate the gear in the retracted position.

5. Fuselage (YHC-1B)

The basic fuselage of the YHC-1B has been retained, together with the rear ramp loading feature.

In order to save drag, the lines of the rear portion of the fuselage have been refaired, resulting in an increase in length. This requires a new rear fuselage structure. At the same time that the rear fuselage is refaired, the pylon is moved aft by 15" to permit the installation of longer blades. Miscellaneous minor fairing will also be used in areas such as heater intake, vents, drains, etc.

Structural Design Considerations

The structural design criteria utilized in the configuration studies pursued in this contract are in agreement with Specification MIL-S-8698 (ASG) "Structural Design Requirements - Helicopters" with minor deviations based on past experience of the contractor with tandem rotor turbine helicopters. Allowable loads and stresses are in accordance with MIL-HDBK-5 "Strength of Metal Aircraft Elements."

All dynamic components have been designed to have unlimited fatigue life for the most critical unaccelerated flight conditions up to the 200 mph design maximum level flight speed. The only exception to this philosophy of unlimited life is in transmission and rotor hub bearings which have finite lives.

Those components of the airframe which are critical for dynamic pressure loads such as cowling, nose enclosure, pylon fairing, etc., are being redesigned to improve the drag characteristics of the aircraft. Appropriate strength increases will be incorporated in the detail design to provide for the higher pressures.

The basic airframe of the Boeing-Vertol 107-II is designed for 2.67 g limit load factors at the aircraft c.g. at 18,450 pounds Basic Design Gross Weight. The landing gear will be redesigned to accommodate the retraction mechanism and will be re-drop tested to ensure adequacy of the design.

Weights Estimation

The weights for the advanced Boeing-Vertol 107 and YHC-1B helicopters are based on aircraft currently in production (Boeing-Vertol 107-II and YHC-1B) modified to reflect the redesign associated with the requirements of the high performance helicopter. The rotor group is a new design and causes the major part of the weight change. Rotor group weights were calculated from layouts of high performance rotor systems for existing helicopters. These weights were then used to adjust Vertol conventional rotor trend curves to reflect the more efficient high performance design.

The addition of retractable landing gear is another significant weight change. The weight penalty for this feature has been estimated from layouts and comparison with similar retraction systems of other aircraft. Weight changes to the fuselage, landing gear, and flight controls, associated with gross weight increase and/or distance between centerlines of the rotors, have been estimated from trend curves. The remaining fairing changes are relatively minor and have been estimated from layout data. The following table summarizes the estimated weight changes.

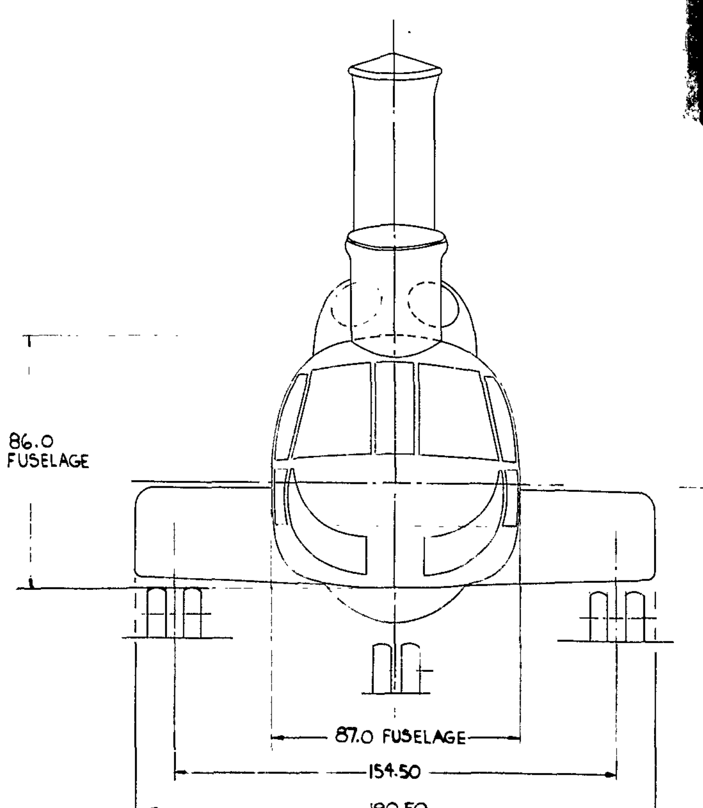
MAJOR WEIGHT CHANGES (Compared to 107-II and YHC-1B)		
Item	Weight Change - Lbs.	
	Advanced 107	Advanced YHC-1B
Rotor Group - Redesign	+188	+400
Body Group - Gross Wt. and Increased Distance Between Rotors	+ 37	+108
Fairing Changes	+ 30	+120
Landing Gear - Retraction	+110	+200
Gross Weight Increase	-	+ 82
Flight Controls - Redesign -	+ 35	-
Gross Weight Increase -	-	+ 25
Total	+400	+937

The design changes mentioned are well within the experience of this contractor. This experience provides a good basis for a reliable prediction of the associated weight changes. Examination of the design layouts and weight trend data indicates that the established target weights for the high performance helicopters can be obtained through the efficient design and close weight control customarily maintained by the Vertol Division of Boeing Airplane Company. A group weight statement appears in the Summary of Weights and Performance in Section V.

Conclusions

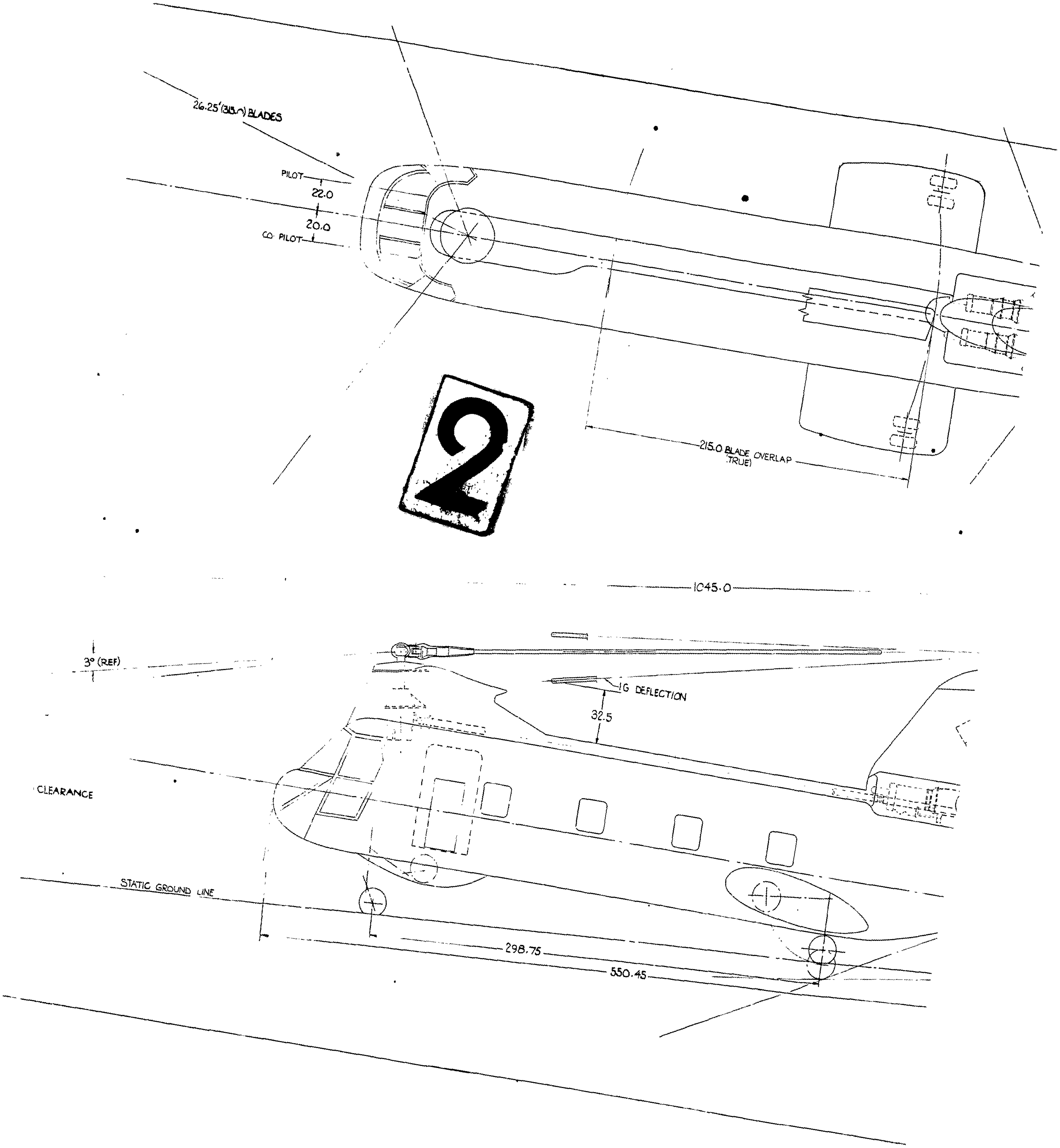
A preliminary design study with associated drawings has been completed. Design areas of major modification in the conversion of the Boeing-Vertol 107 to the advanced 107 are established. Although the advanced YHC-1B was not studied in such design detail, the basic changes required are quite similar. The weights of the high performance versions are based, in most part, upon actual weights of detailed design drawings of each configuration and supplemented by analysis of layouts of areas requiring major modification. It is concluded that design changes and modifications to achieve the high performance configuration are readily achievable with present knowledge and without extensive development programs.

1

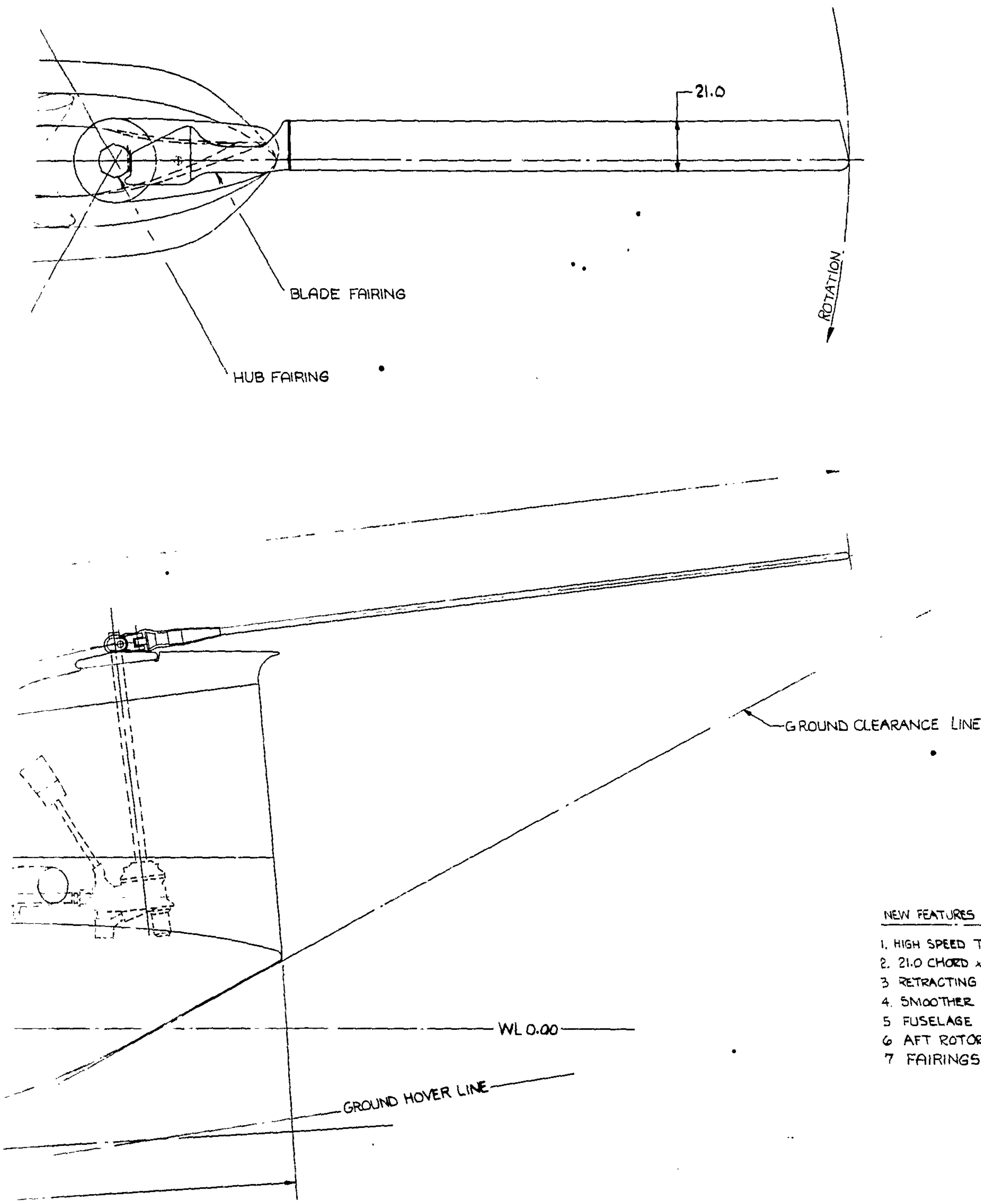


86.0
FUSELAGE
87.0 FUSELAGE
154.50
180.50

ROTATION
3°
16.19
13.10
108.57 GROUND CLEARANCE
AT 1 G



26.25' (315 in) BLADES
PILOT
22.0
20.0
CO PILOT
215.0 BLADE OVERLAP
(TRUE)
2
1045.0
3° (REF)
1G DEFLECTION
32.5
CLEARANCE
STATIC GROUND LINE
298.75
550.45

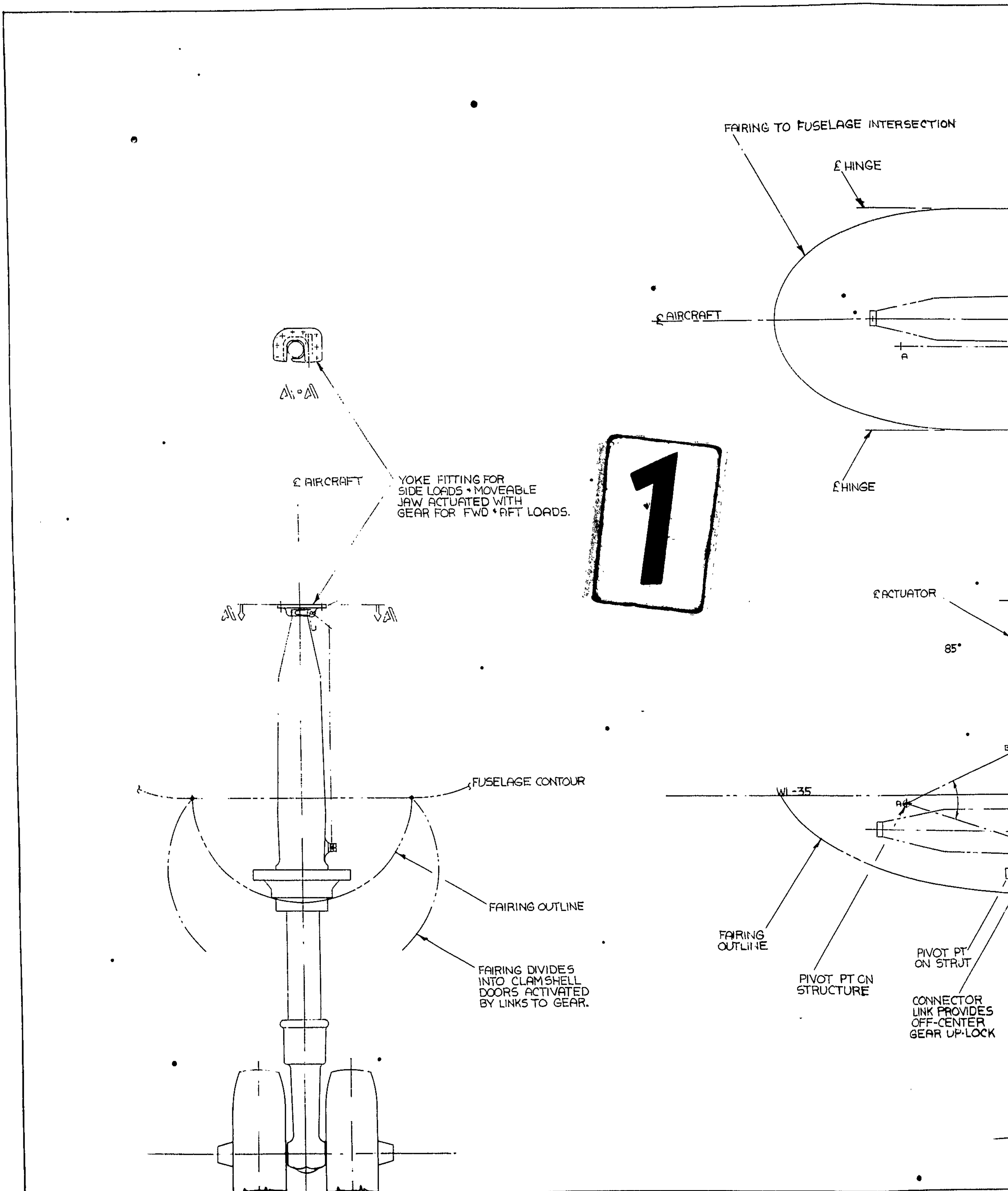


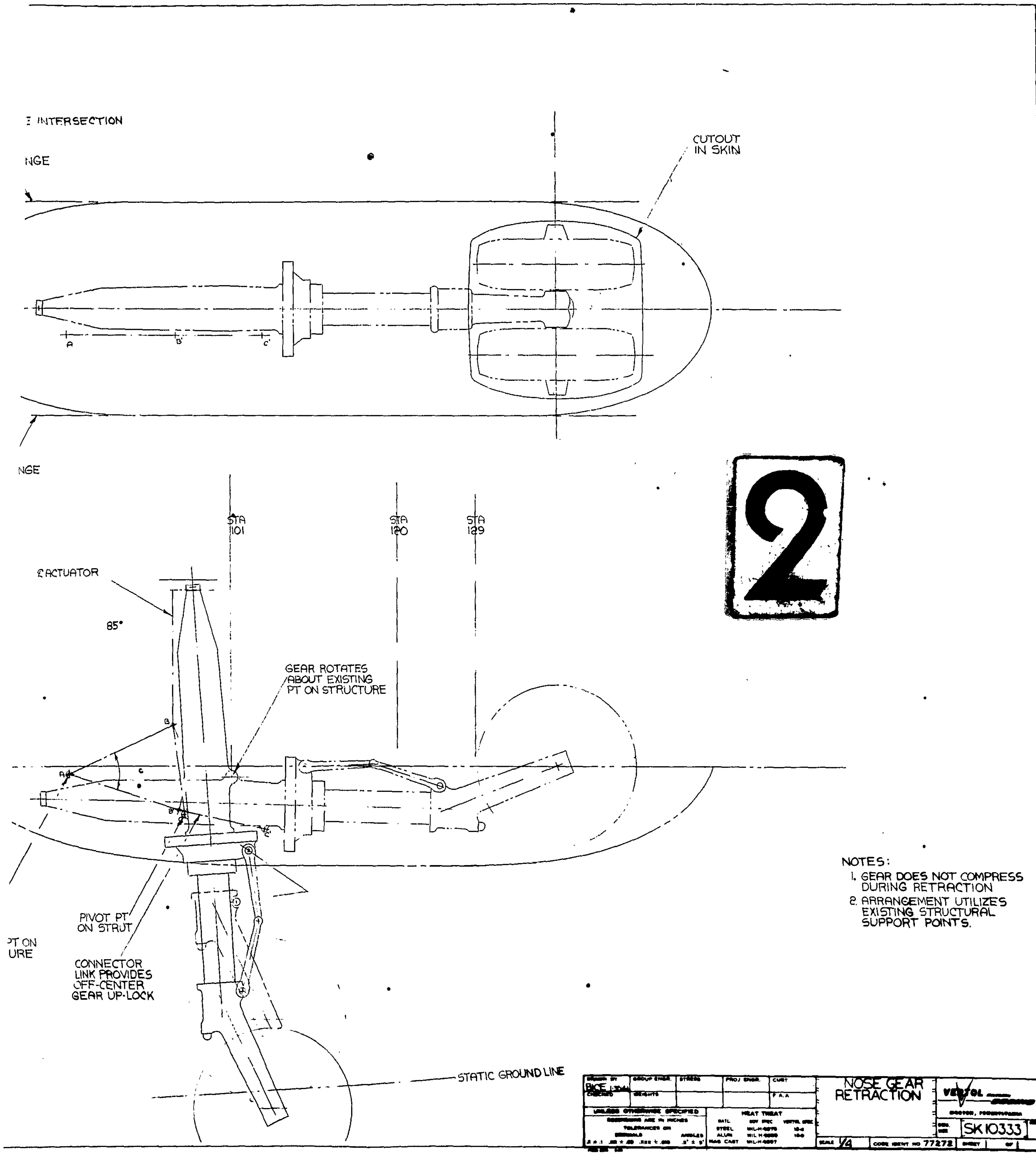
3

NEW FEATURES FOR THE ADVANCED 107-II

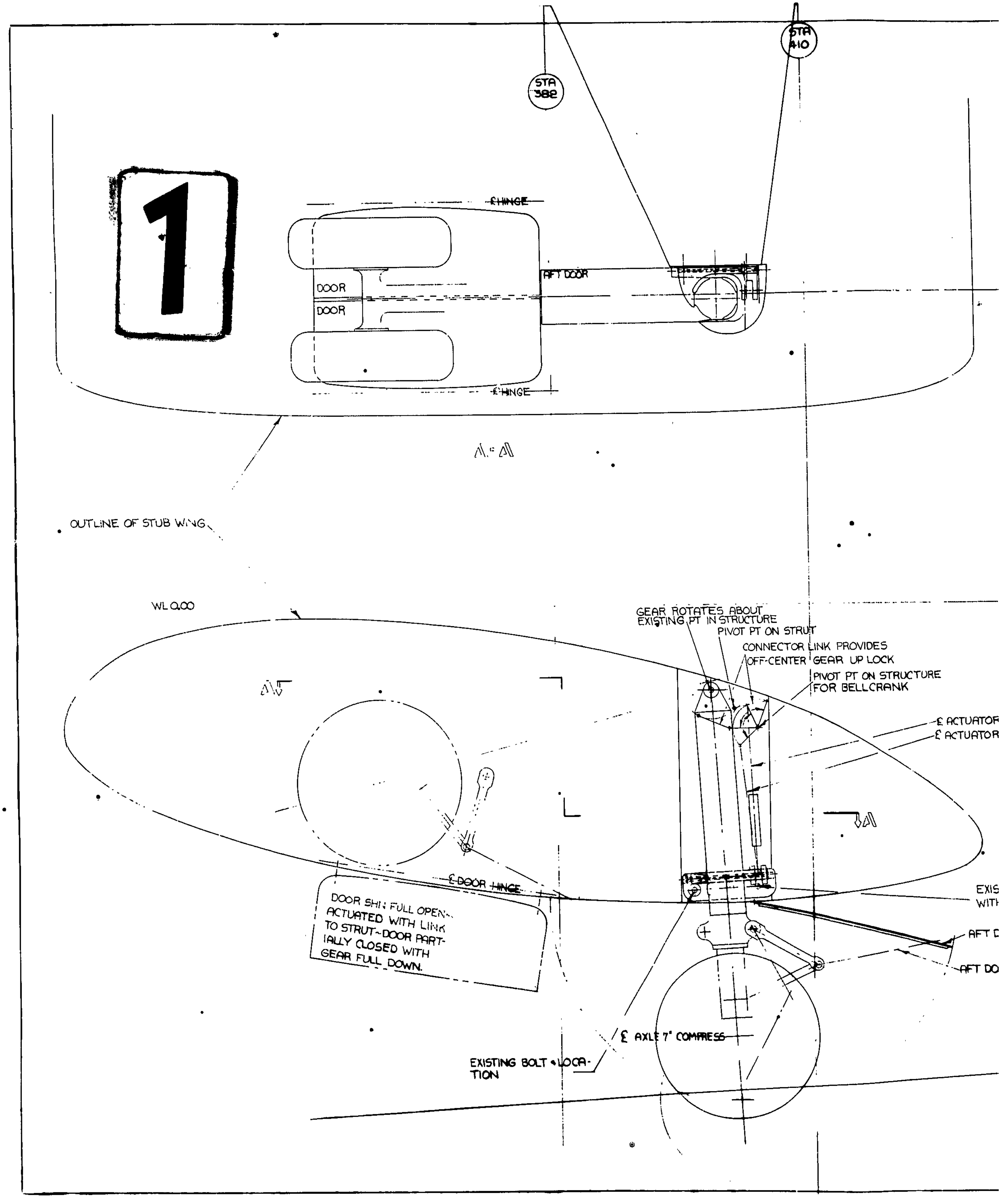
1. HIGH SPEED TAIL CONFIGURATION
2. 21.0 CHORD x 315.0 (26'-3") LONG ROTOR BLADES
3. RETRACTING LANDING GEAR.
4. SMOOTHER EXTERIOR SURFACE IN COCKPIT GLASS AREA
5. FUSELAGE LENGTH INCREASED 15.0
6. AFT ROTOR HEIGHT INCREASED 10.0
7. FAIRINGS FOR ROTOR BLADES + HUB.

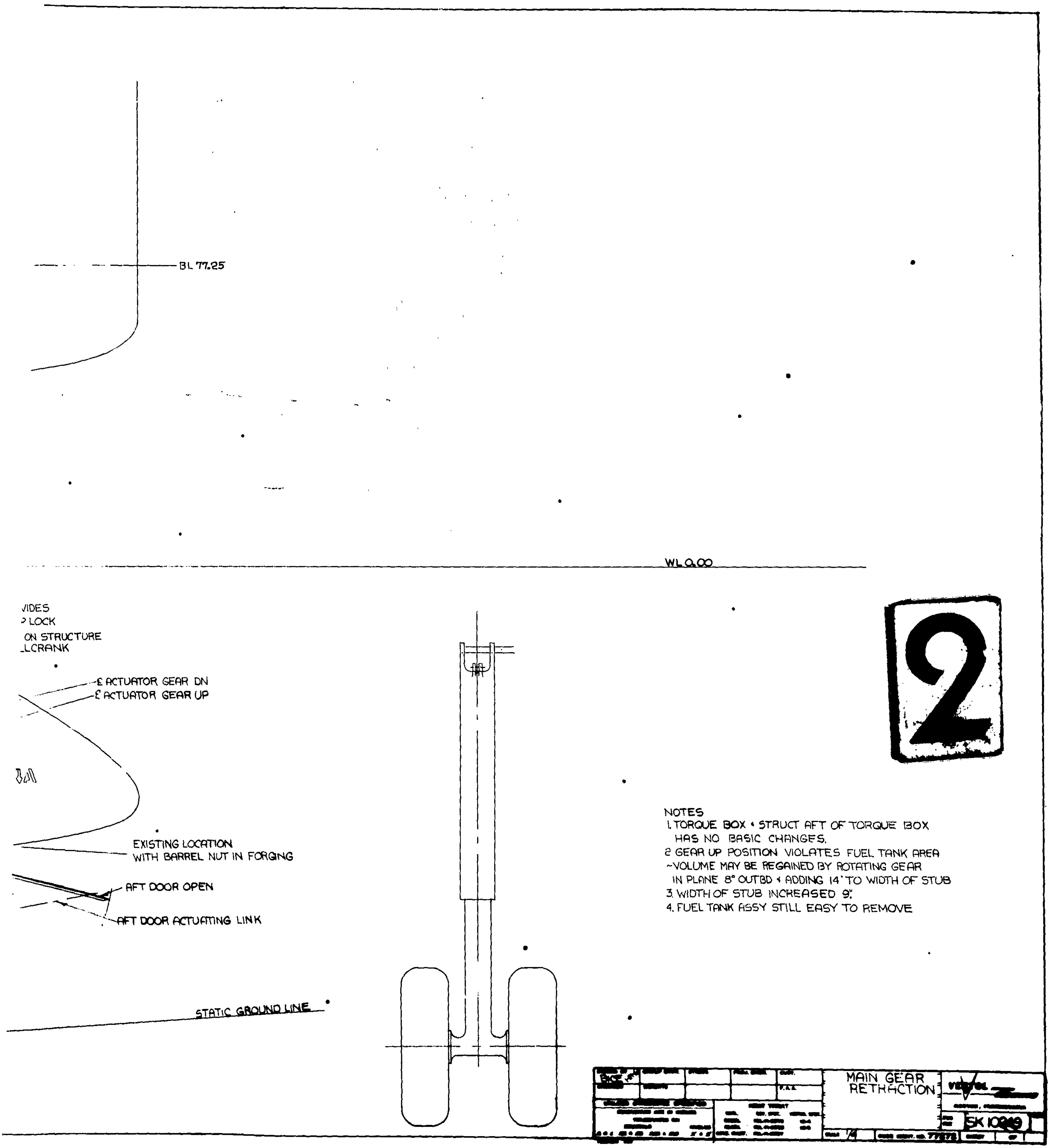
CHECKED	WEIGHTS			F.A.A.	ADVANCED 107-II	VERTOL
UNLESS OTHERWISE SPECIFIED		HEAT TREAT				SK10315
DIMENSIONS ARE IN INCHES		MATL	GOV SPEC	VERTOL SPEC		
TOLERANCES ON DECIMALS / ANGLES		STEEL				
		ALUM				
		MAG CAST			SCALE 1/20	CODE IDENT NO 77272 · SHEET 1 OF 1


FAIRING TO FUSELAGE INTERSECTION
℄ HINGE
℄ AIRCRAFT
℄ HINGE
A-A
℄ AIRCRAFT
YOKE FITTING FOR SIDE LOADS + MOVEABLE JAW ACTUATED WITH GEAR FOR FWD + AFT LOADS.
1
℄ ACTUATOR
85°
FUSELAGE CONTOUR
WL -35
FAIRING OUTLINE
FAIRING DIVIDES INTO CLAMSHELL DOORS ACTIVATED BY LINKS TO GEAR.
FAIRING OUTLINE
PIVOT PT ON STRUCTURE
PIVOT PT ON STRUT
CONNECTOR LINK PROVIDES OFF-CENTER GEAR UP-LOCK

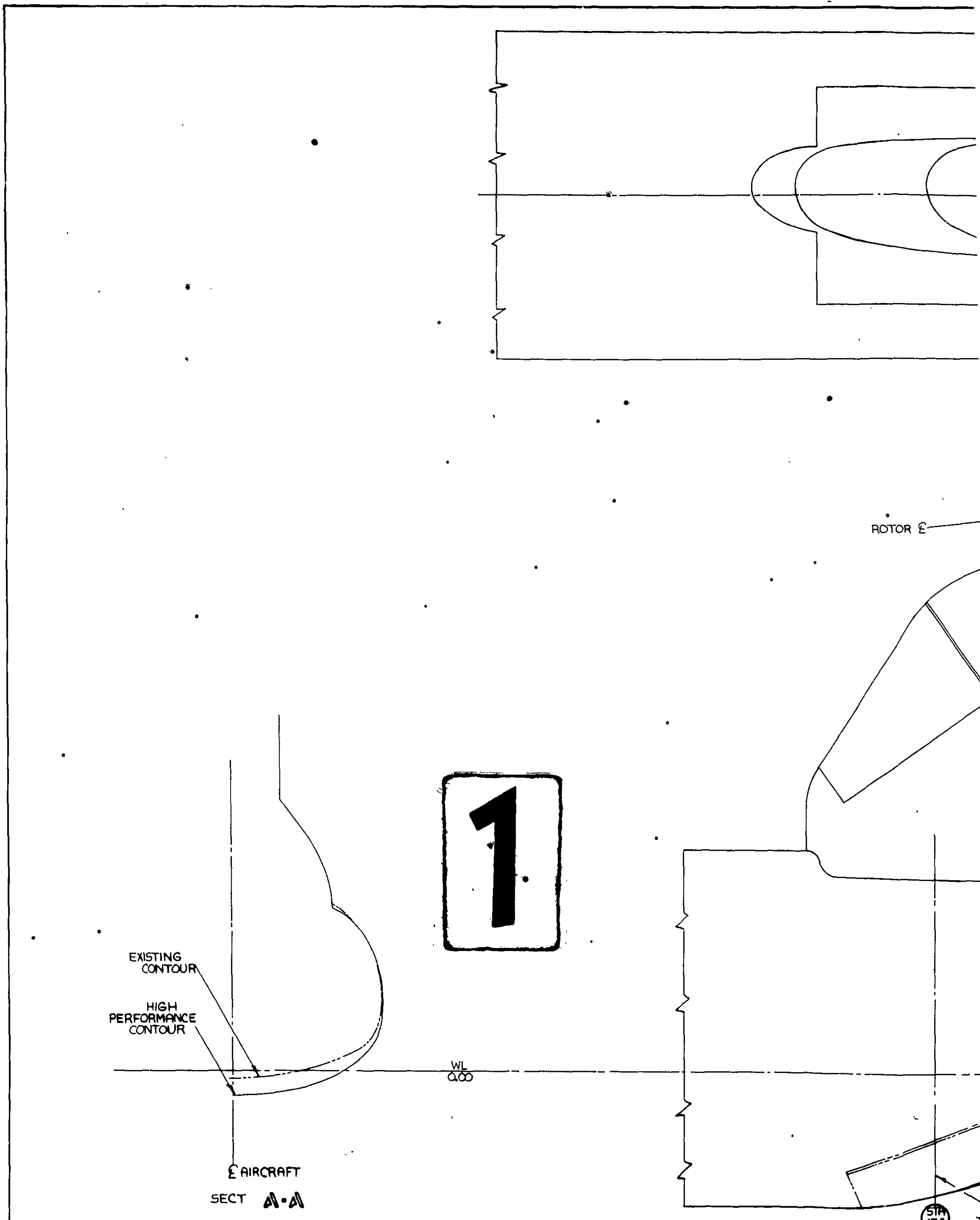


INTERSECTION
NGE
CUTOUT IN SKIN
A
B'
C'
NGE
2
STA 101
STA 120
STA 129
℄ ACTUATOR
85°
GEAR ROTATES ABOUT EXISTING PT ON STRUCTURE
B
C
A
B'
C'
PIVOT PT ON STRUT
PT ON URE
CONNECTOR LINK PROVIDES OFF-CENTER GEAR UP-LOCK
STATIC GROUND LINE
NOTES:
1. GEAR DOES NOT COMPRESS DURING RETRACTION
2. ARRANGEMENT UTILIZES EXISTING STRUCTURAL SUPPORT POINTS.
NOSE GEAR RETRACTION
VERTOL
SK10333
SCALE 1/4
CODE IDENT NO 77272
HEAT TREAT
STEEL
ALUM
MAG CAST

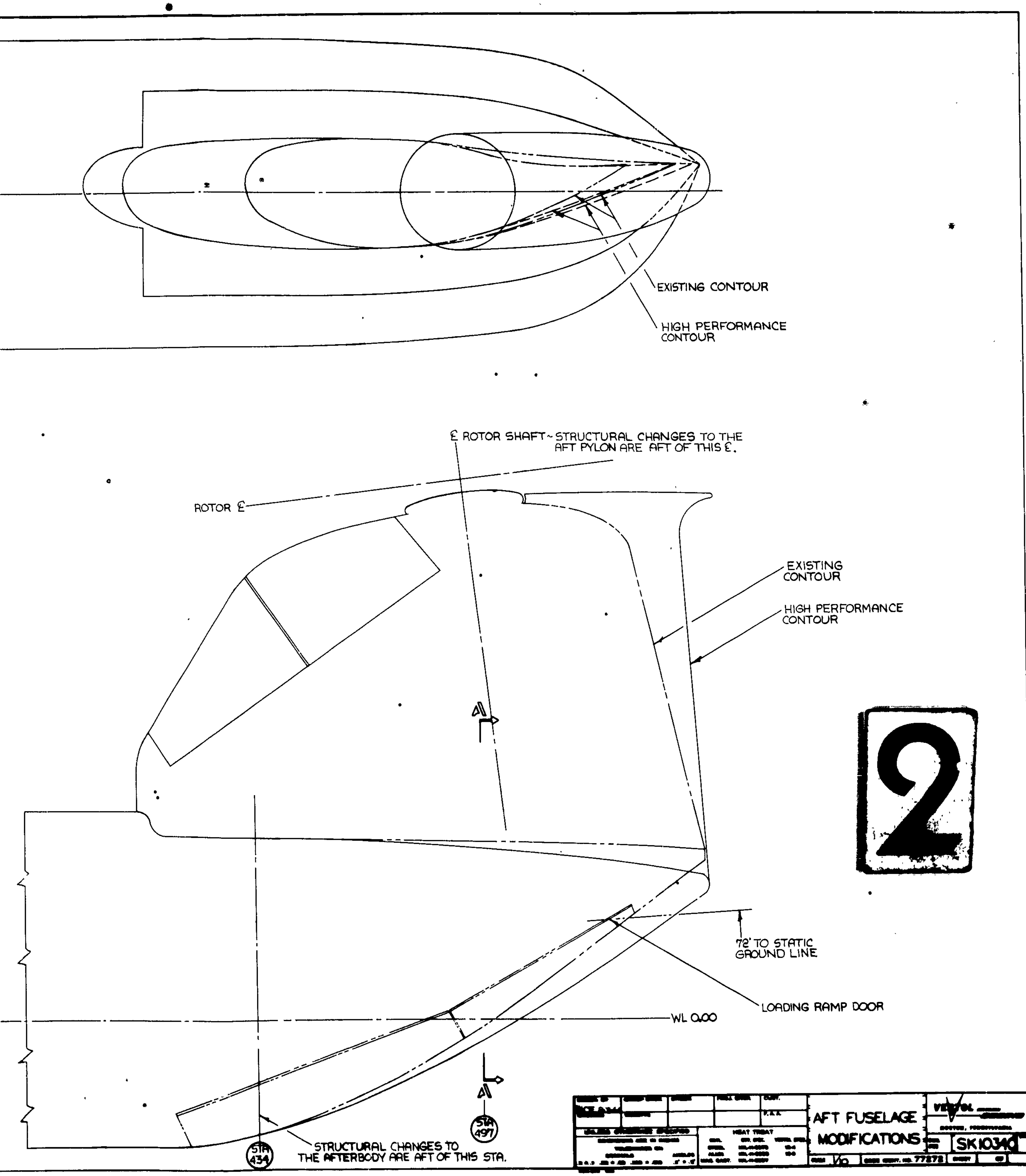

1
STA 382
STA 410
℄ HINGE
DOOR
DOOR
AFT DOOR
℄ HINGE
A - A
OUTLINE OF STUB WING
WL 0.00
GEAR ROTATES ABOUT EXISTING PT IN STRUCTURE
PIVOT PT ON STRUT
CONNECTOR LINK PROVIDES OFF-CENTER GEAR UP LOCK
PIVOT PT ON STRUCTURE FOR BELLCRANK
℄ ACTUATOR
℄ ACTUATOR
℄ DOOR HINGE
DOOR SHN FULL OPEN- ACTUATED WITH LINK TO STRUT-DOOR PARTIALLY CLOSED WITH GEAR FULL DOWN.
℄ AXLE 7" COMPRESS
EXISTING BOLT LOCATION

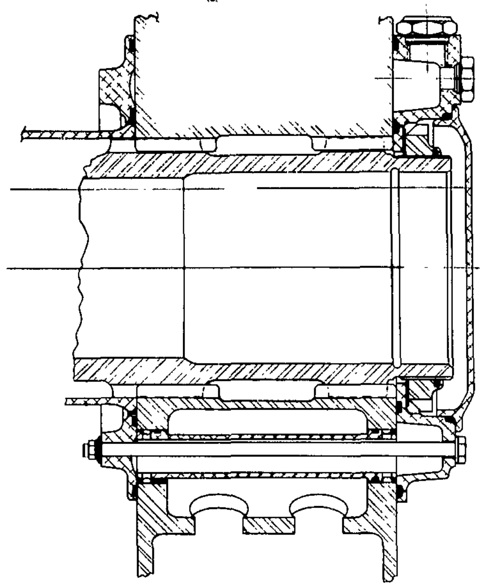


NOTES
1. TORQUE BOX & STRUCT AFT OF TORQUE BOX HAS NO BASIC CHANGES.
2. GEAR UP POSITION VIOLATES FUEL TANK AREA ~VOLUME MAY BE REGAINED BY ROTATING GEAR IN PLANE 8° OUTBD & ADDING 14" TO WIDTH OF STUB
3. WIDTH OF STUB INCREASED 9".
4. FUEL TANK ASSY STILL EASY TO REMOVE

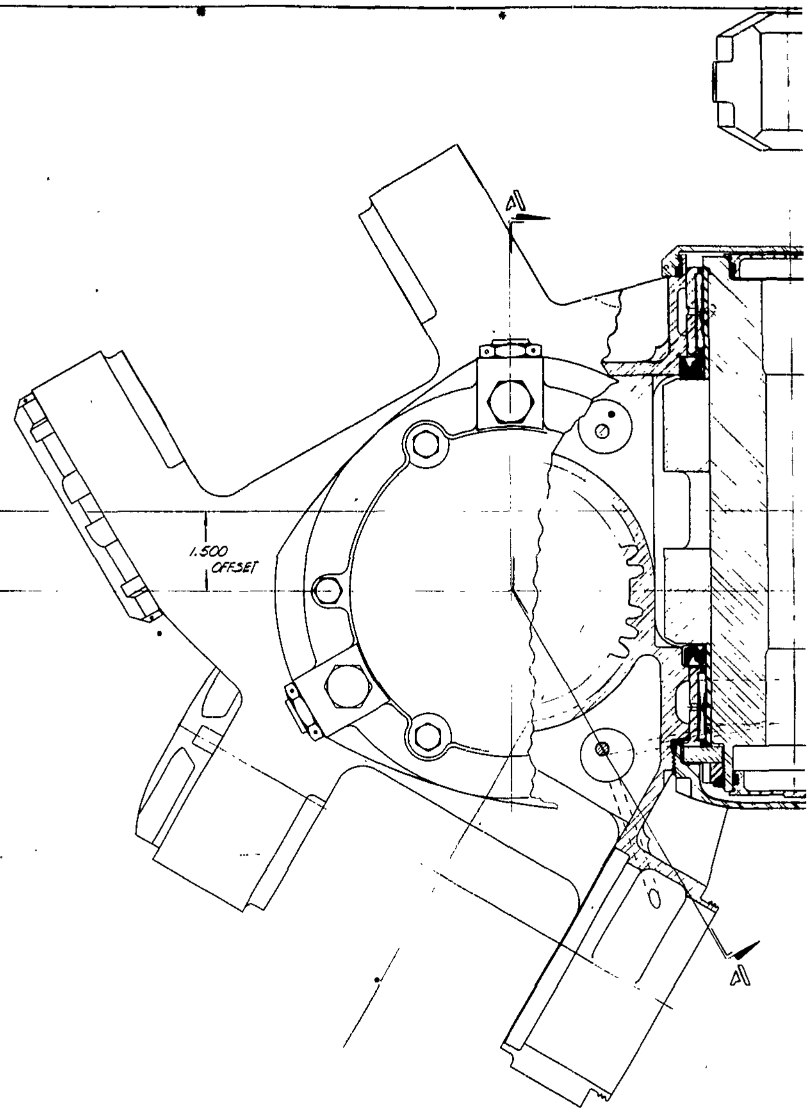


ROTOR ℄
1
EXISTING CONTOUR
HIGH PERFORMANCE CONTOUR
WL 0.00
℄ AIRCRAFT
SECT A-A
STA 434

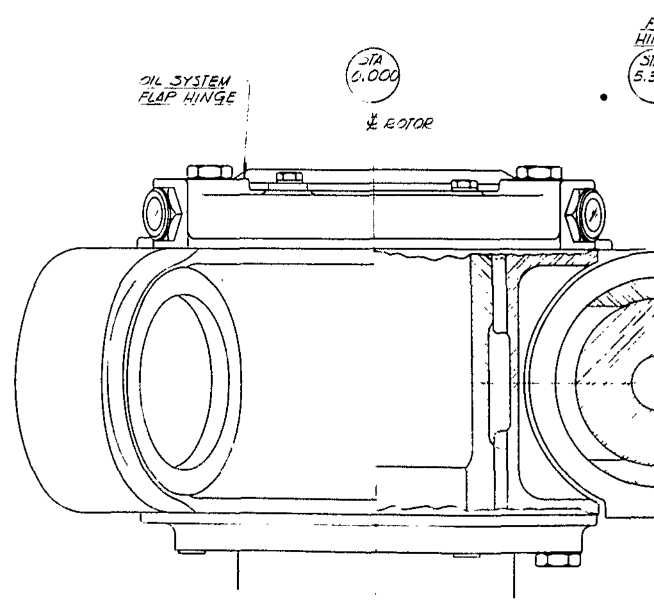

EXISTING CONTOUR
HIGH PERFORMANCE CONTOUR
℄ ROTOR SHAFT ~ STRUCTURAL CHANGES TO THE AFT PYLON ARE AFT OF THIS ℄.
ROTOR ℄
EXISTING CONTOUR
HIGH PERFORMANCE CONTOUR
A
2
72" TO STATIC GROUND LINE
LOADING RAMP DOOR
WL 0.00
A
STA 497
STA 434
STRUCTURAL CHANGES TO THE AFTERBODY ARE AFT OF THIS STA.
AFT FUSELAGE MODIFICATIONS
VERTOL
SK10340
1/10
77272



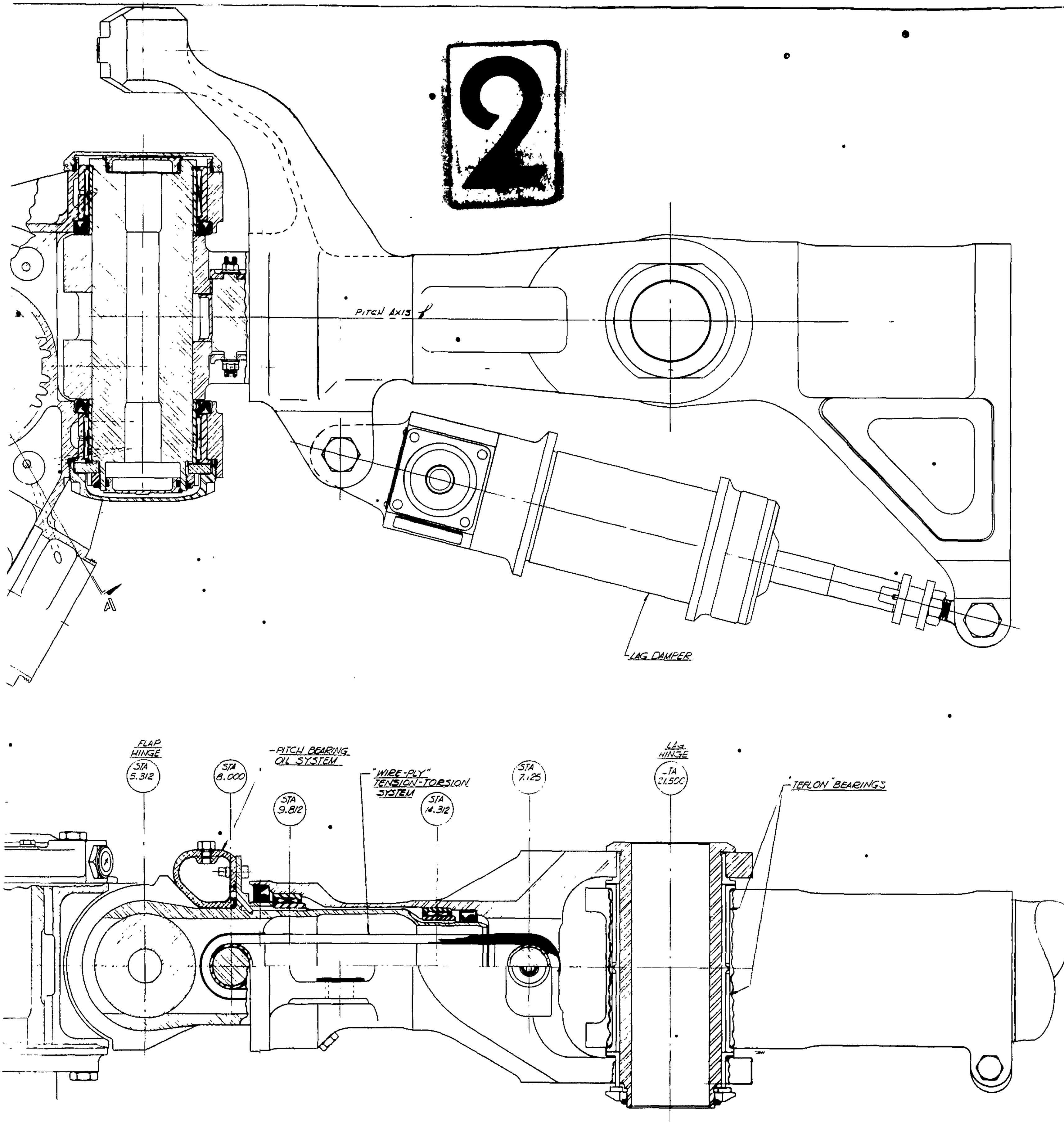
SECTION A-A



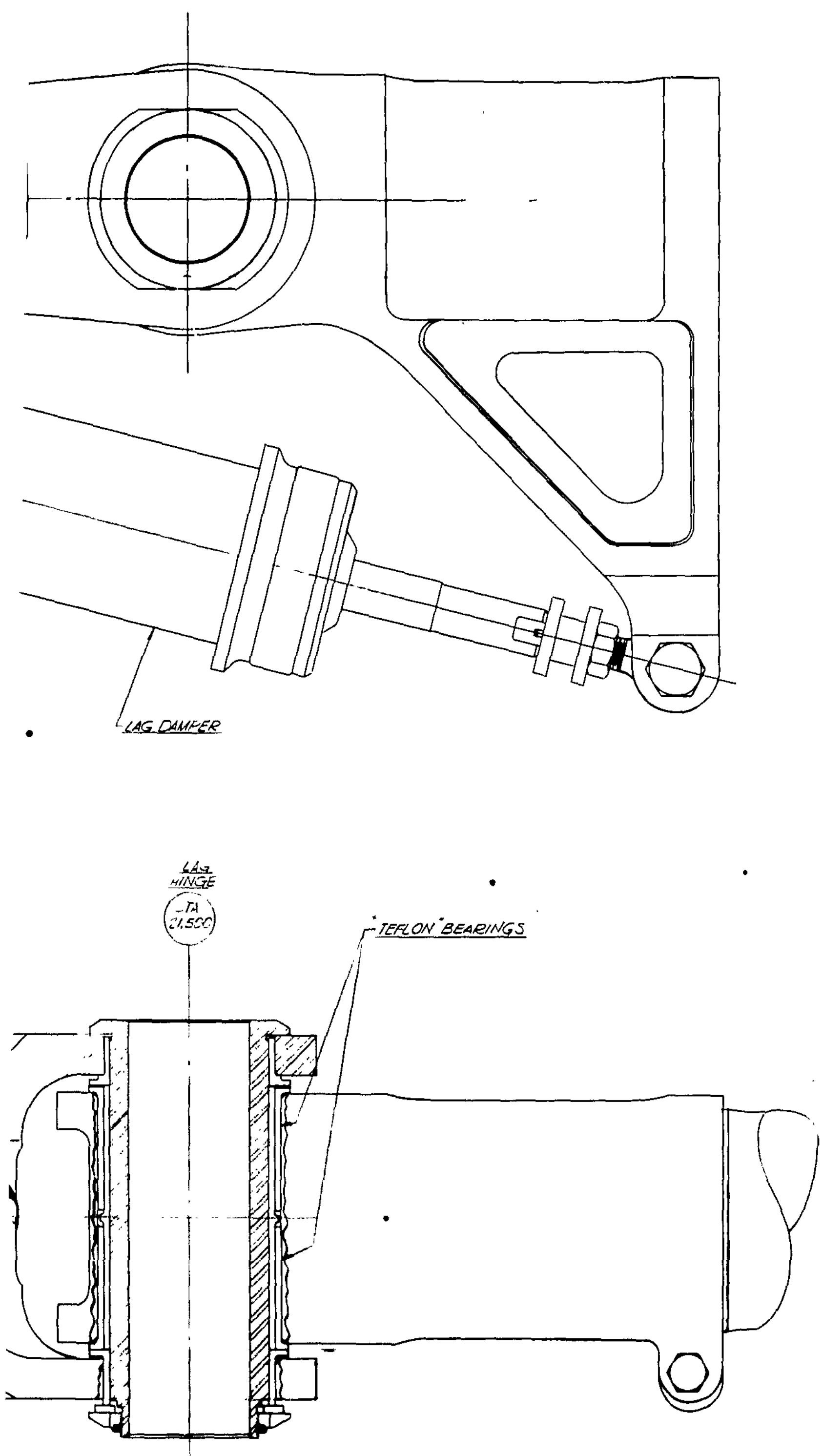
1



2



PITCH AXIS
LAG DAMPER
A
FLAP HINGE
STA 5.312
STA 8.000
PITCH BEARING OIL SYSTEM
"WIRE-PLY" TENSION-TORSION SYSTEM
STA 9.812
STA 14.312
STA 7.125
LAG HINGE
STA 21.500
"TEFLON" BEARINGS



3

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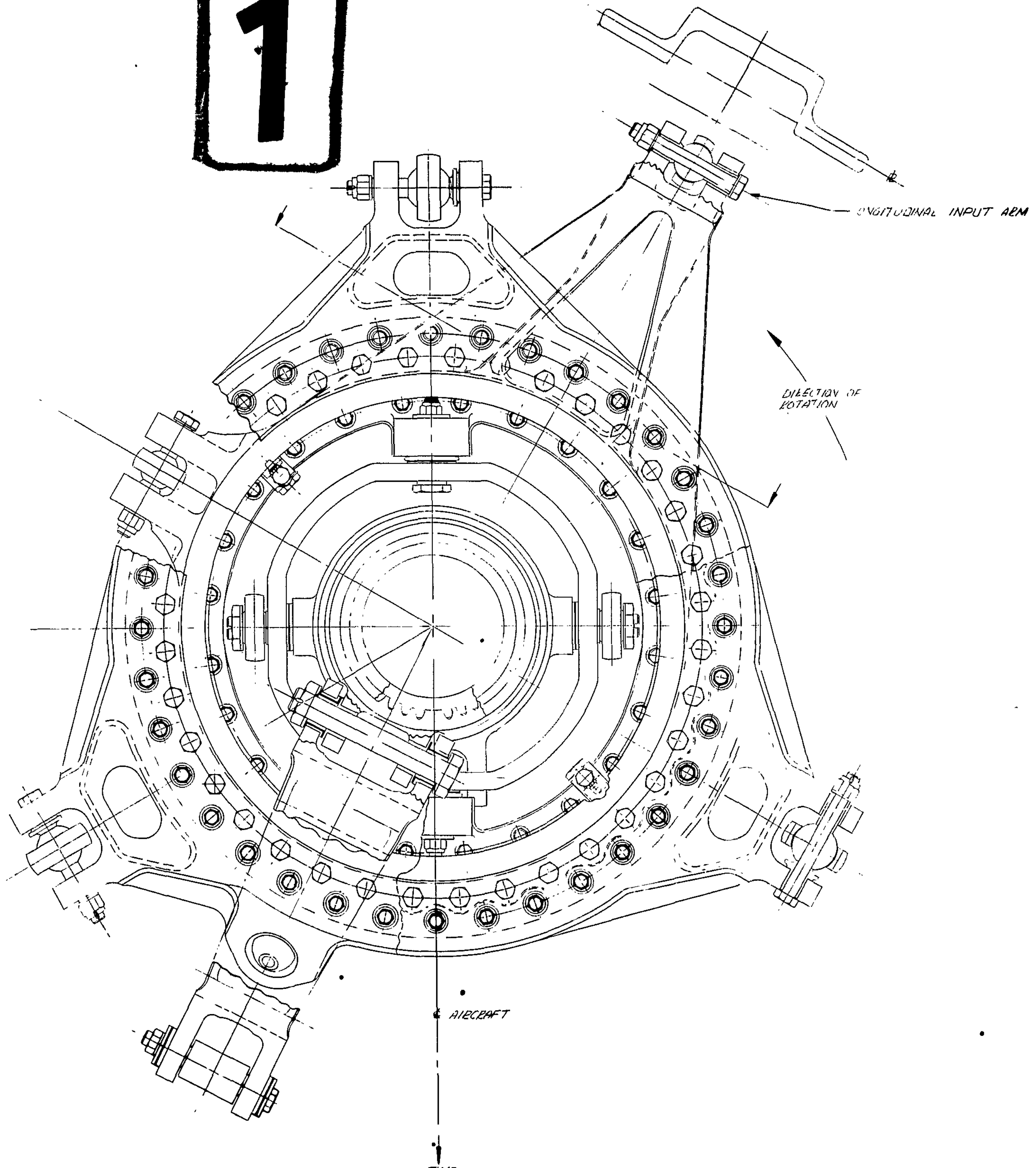
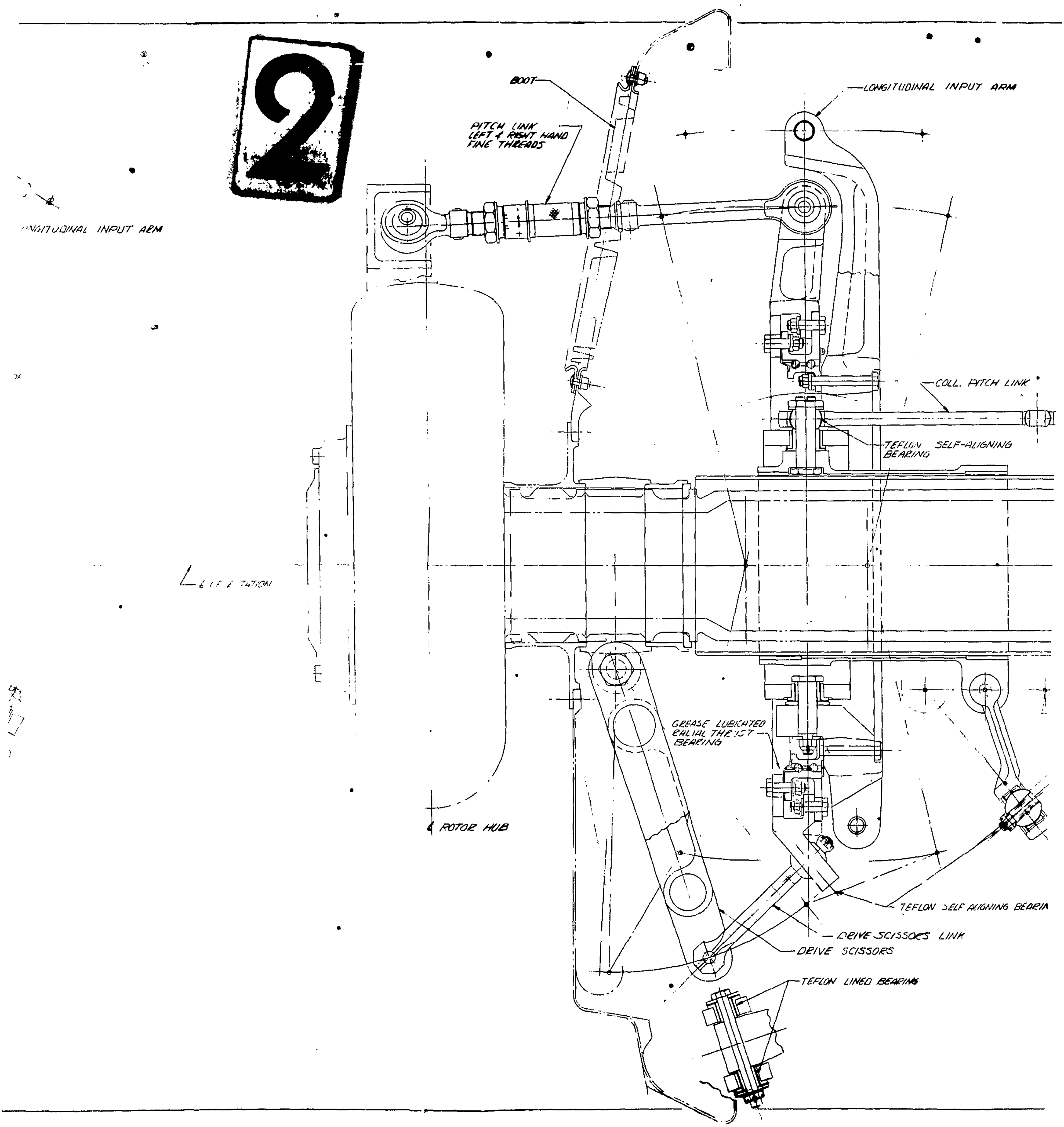
DRAWN BY	GROUP ENGR	STRESS	PROJ ENGR	CUST		
CHECKED	WEIGHTS	CALVERT		F.A.A.	ROTOR HUB	VERTOL DIVISION, MORTON, PENNSYLVANIA
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS ANGLES	HEAT TREAT					DWG SIZE SK10307 REV
					SCALE FULL	CODE IDENT NO. 77272 SHEET OF

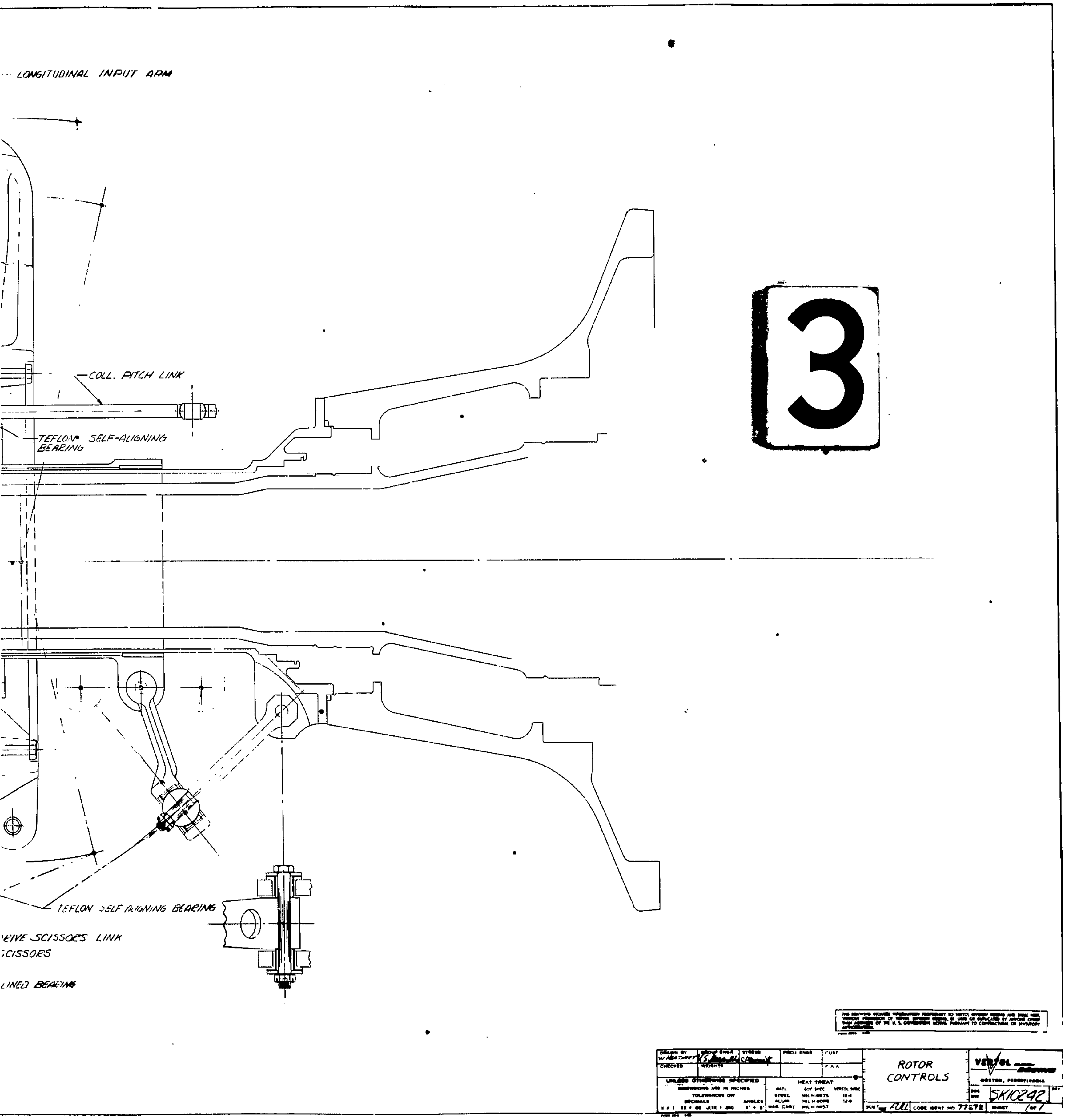
1



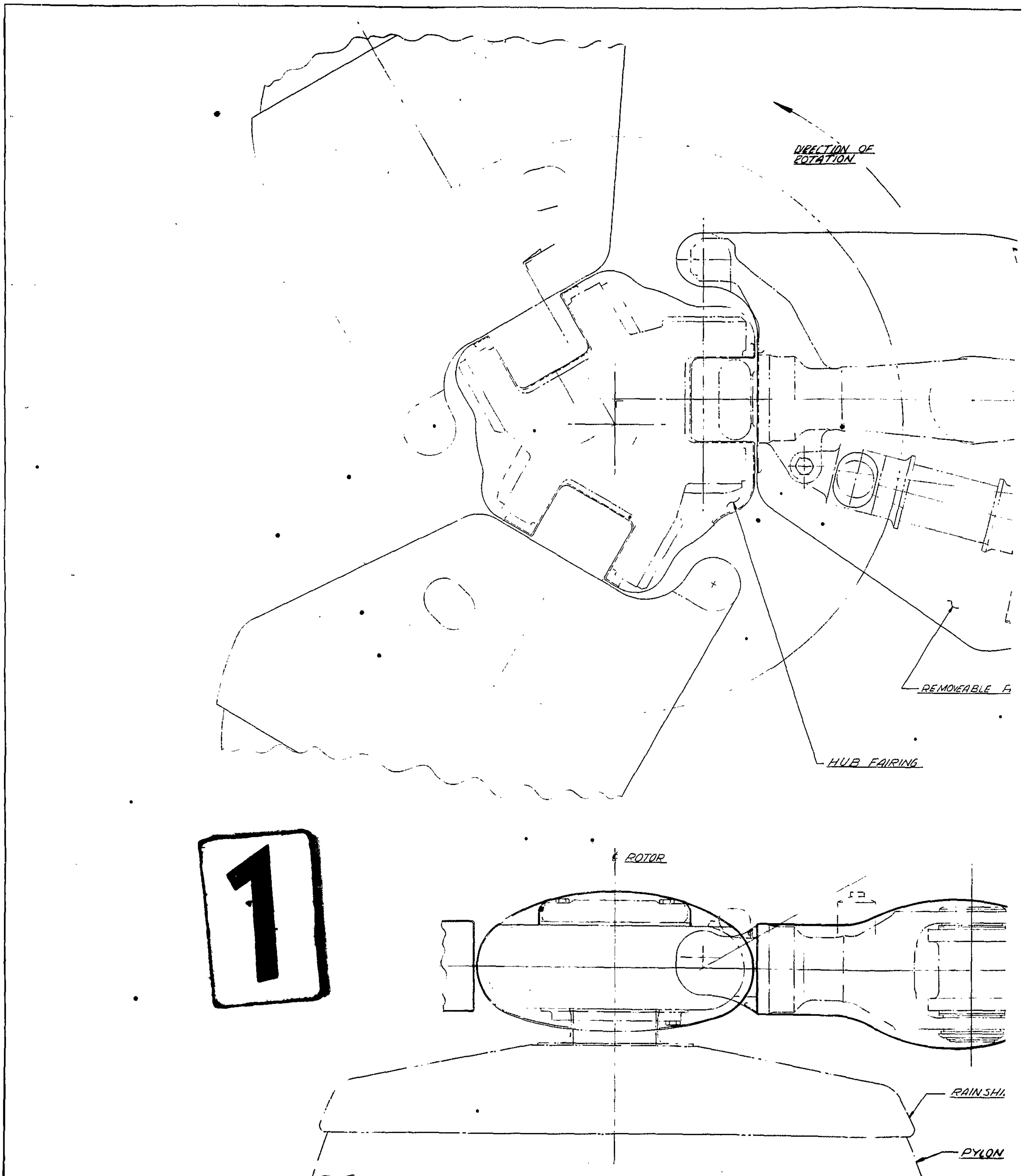
LONGITUDINAL INPUT ARM
DIRECTION OF
ROTATION
℄ AIRCRAFT
FWD.

2

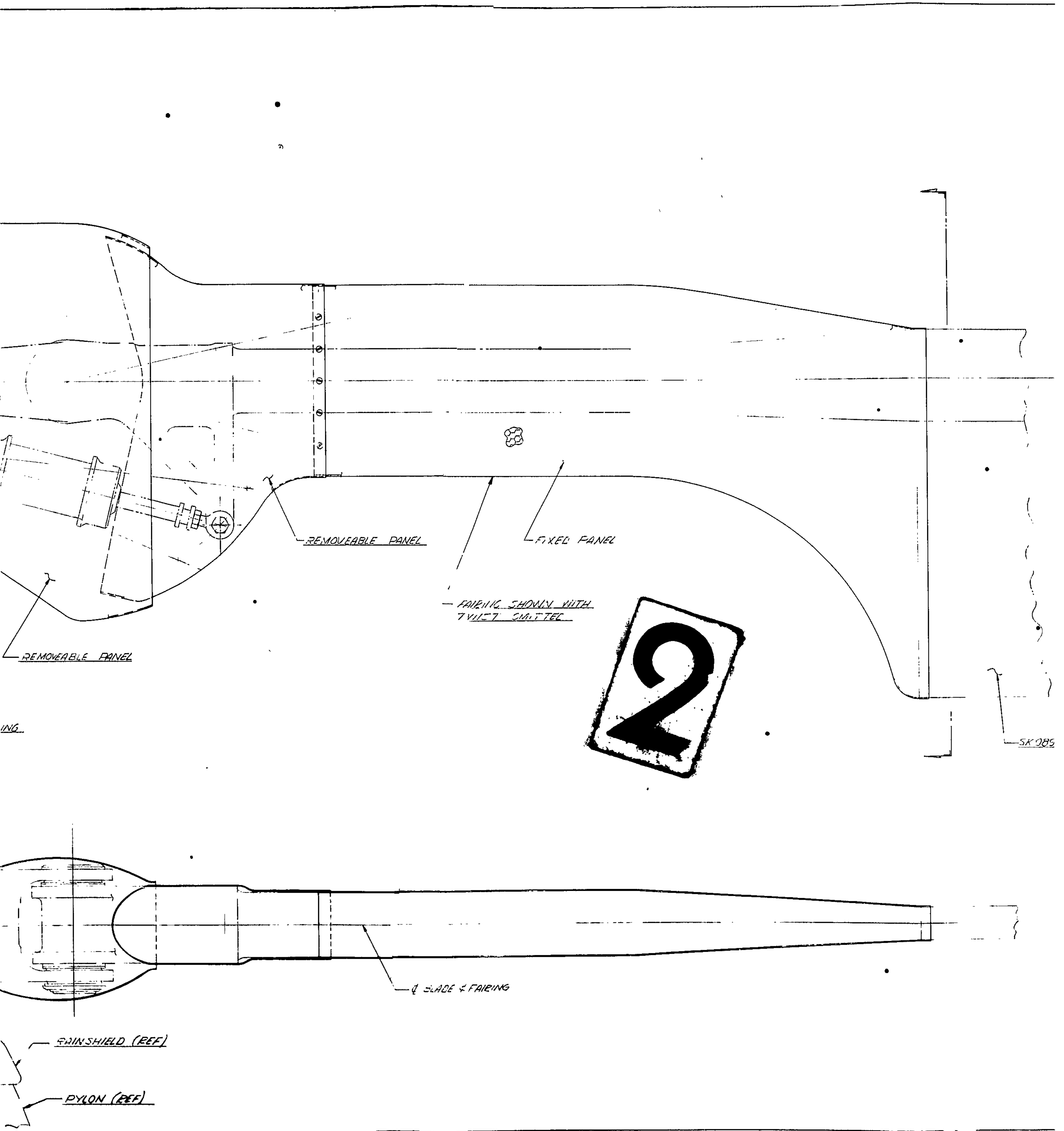

BOOT
PITCH LINK
LEFT & RIGHT HAND
FINE THREADS
LONGITUDINAL INPUT ARM
COLL. PITCH LINK
TEFLON SELF-ALIGNING BEARING
GREASE LUBICATED
RADIAL THRUST
BEARING
ROTOR HUB
TEFLON SELF ALIGNING BEARIN
DRIVE SCISSORS LINK
DRIVE SCISSORS
TEFLON LINED BEARING



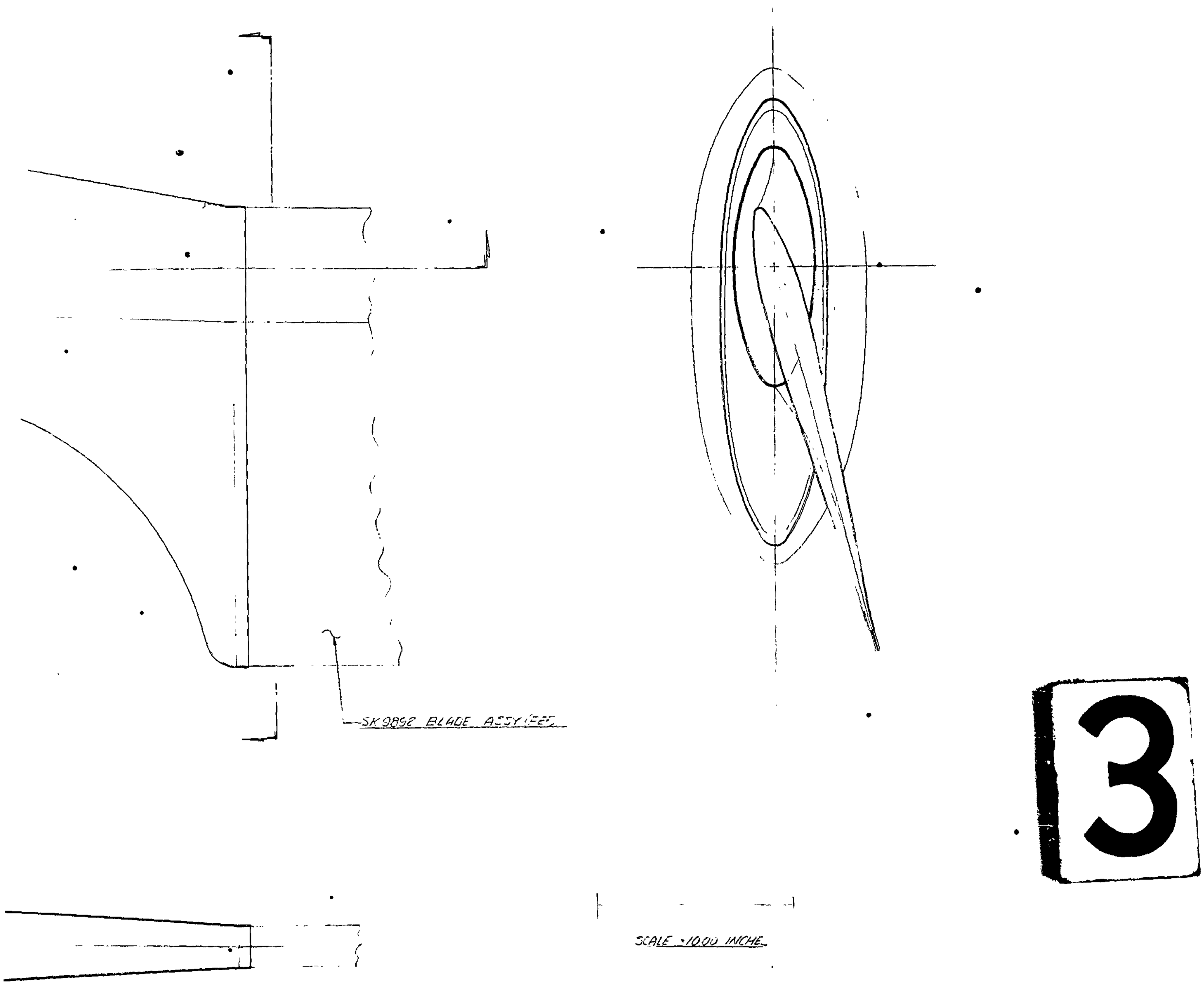
LONGITUDINAL INPUT ARM
COLL. PITCH LINK
TEFLON SELF-ALIGNING BEARING
TEFLON SELF ALIGNING BEARING
SCISSORS LINK
LINED BEARING
3
DRAWN BY
W MARTINET
GROUP ENGR
STRESS
PROJ ENGR
CUST
CHECKED
WEIGHTS
F A A
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
HEAT TREAT
STEEL MIL H-6875
ALUM MIL H 6088
MAG CAST MIL H 6857
ROTOR CONTROLS
VERTOL
SK10242
SCALE FULL
CODE IDENT NO 77272
SHEET 1 OF 1



DIRECTION OF ROTATION
REMOVEABLE F
HUB FAIRING
1
℄ ROTOR
RAINSHI
PYLON



REMOVEABLE PANEL
FIXED PANEL
FAIRING SHOWN WITH
TWIST OMITTED
REMOVEABLE PANEL
2
℄ BLADE & FAIRING
RAINSHIELD (REF)
PYLON (REF)



W. NEATHES

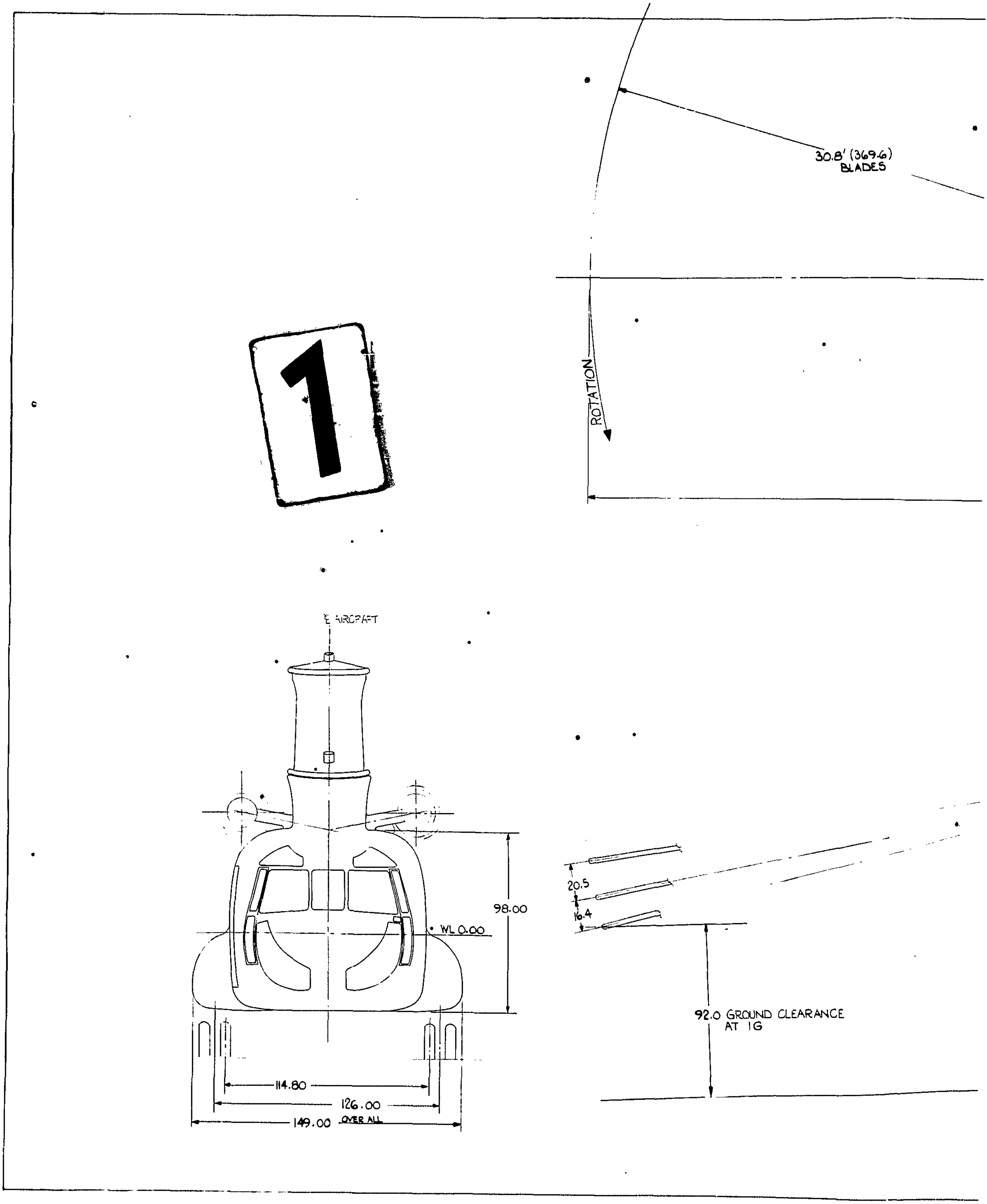
CA.

ROTOR HUB
FAIRING

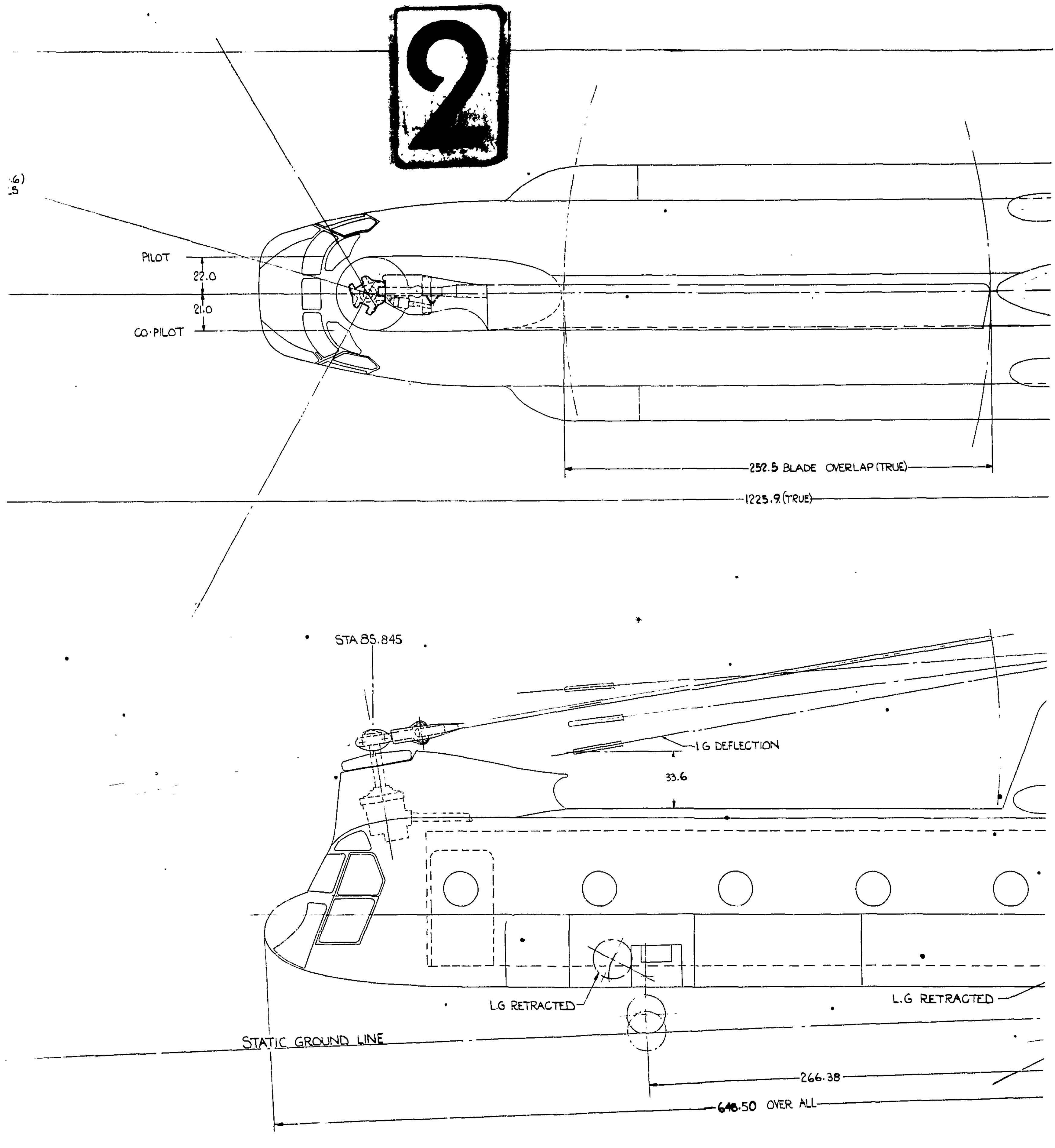
SK10319

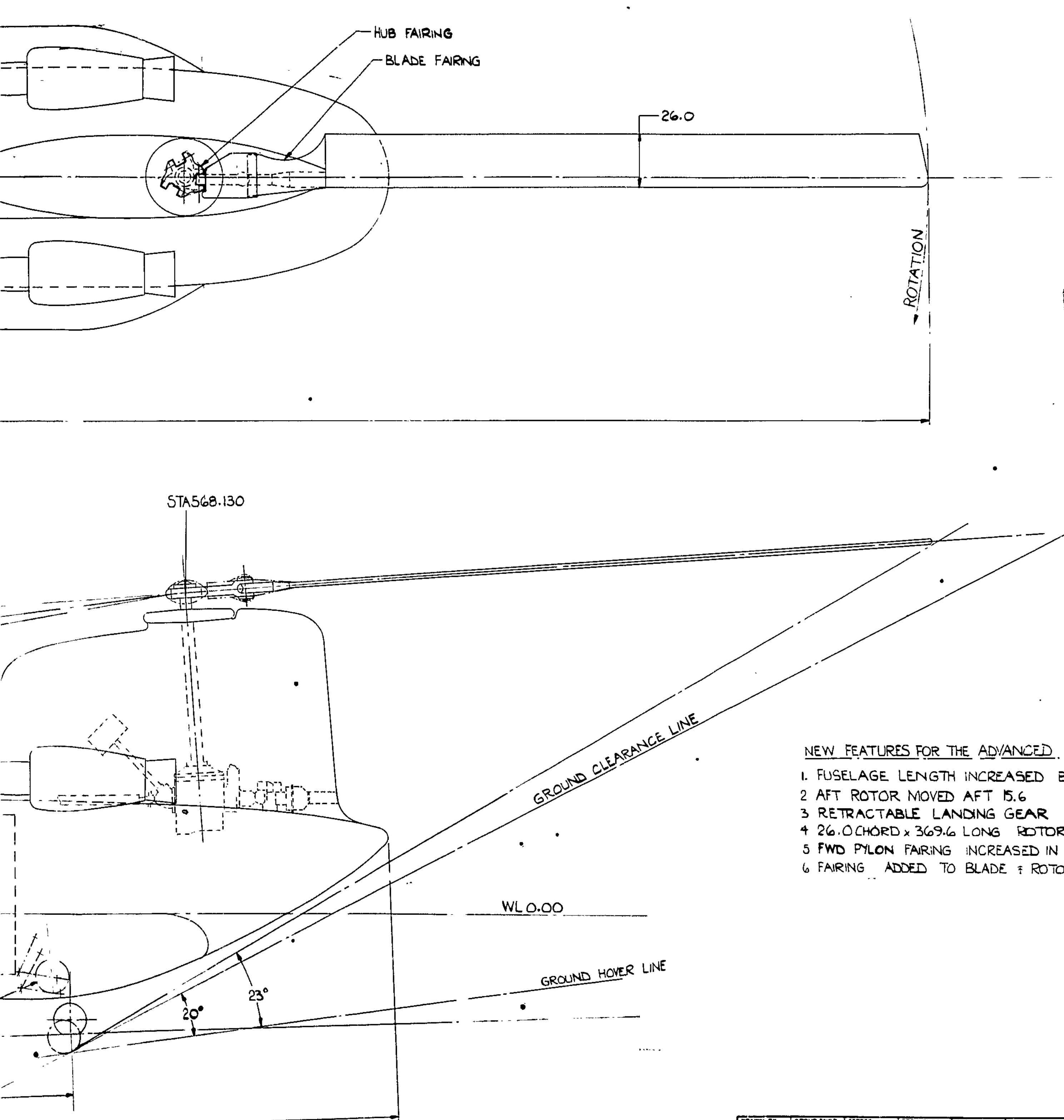
77272

1 of 1



1
30.8' (369.6)
BLADES
ROTATION
℄ AIRCRAFT
98.00
WL 0.00
20.5
16.4
92.0 GROUND CLEARANCE
AT 1G
114.80
126.00
149.00
OVER ALL


2
PILOT
22.0
21.0
CO-PILOT
252.5 BLADE OVERLAP (TRUE)
1225.9 (TRUE)
STA 85.845
1 G DEFLECTION
33.6
L.G RETRACTED
L.G RETRACTED
STATIC GROUND LINE
266.38
648.50 OVER ALL



3

NEW FEATURES FOR THE ADVANCED YHC-1B

1. FUSELAGE LENGTH INCREASED BY 39.5
2. AFT ROTOR MOVED AFT 15.6
3. RETRACTABLE LANDING GEAR
4. 26.0 CHORD x 369.6 LONG ROTOR BLADES
5. FWD PYLON FAIRING INCREASED IN LENGTH.
6. FAIRING ADDED TO BLADE & ROTOR HUB

DRAWN BY METCALFE	GROUP ENGR	STRESS	PROJ ENGR	CUST	ADVANCED YHC-1B
CHECKED	WEIGHTS			F A A	

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON DECIMALS X ± 1 XX ± .03 XXX ± .010 ANGLES X 5

HEAT TREAT		
MAT'L	GOV SPEC	VERTOL SPEC
STEEL	MIL-H-6875	12-4
ALUM	MIL-H-6088	12-9
MAG CAST	MIL-H-6857	

VERTOL

DWG. SIZE SK1031

SCALE 1/20 CODE IDENT NO 77272 SHEET 1 OF

SUMMARY OF WEIGHTS AND PERFORMANCE

Introduction

The purpose of this section is to present further performance aspects of the advanced versions of the 107 and Chinook series helicopters. Comparison to the present Boeing-Vertol 107 and YHC-1B is made.

1. A study version of the present 107 is the base point for comparisons of performance improvements. This helicopter employs two T58-8 power plants, has 25 ft. blade radius with 18-inch chord blades using the 0012 airfoil section, and has a gross weight of 15,250 pounds at a hover ceiling of 6000 feet, 95°F OGE.

2. The advanced 107 with increased blade radius of 26.25 feet and increased chord of 21 inches, same power. The increased radius allows a greater hovering thrust at the present ratings of the T58-8 engines and thus offers an approach to recouping the useful load lost to empty weight increase. A more complete discussion of this design factor was presented in Section II. Drag reduction yields an equivalent flat-plate area of 20.5 ft^2.

An identical comparison of configurations is presented between the present and advanced YHC-1B. Radius increase here is from 29.5 to 30.8 feet with chords of 23 and 26 inches respectively. Drag reduction yields an equivalent flat plate area of 25.2 ft^2.

Reference 1 presents two intermediate configurations in the progression from present to advanced versions. The effect of chord increases without radius increases and the effect of increases in power available along with further drag reduction.

Performance and associated weights are presented on the following pages for the present and advance versions of the 107 and Chinook series. It is seen that, overall, the Chinook series leads to better performance gains than the 107 series.

SUMMARY OF WEIGHTS AND PERFORMANCE

		Unit	107 SERIES: Boeing-Vertol 107	107 SERIES: Advanced 107	CHINOOK SERIES: YHC-1B	CHINOOK SERIES: Advanced YHC-1B
DESCRIPTION	Rotor Radius/Rotor Solidity	ft / -	25/.0573	26.25/.0636	29.5/.0620	30.8/.0672
	Rotor Chord/No. of Blades	in/ -	18/3	21/3	23/3	26/3
	Rotor Twist/Rotor Tip Speed	deg. /fps	-8.33/690	-14/655	-9/710	-14/675
	Rotor Airfoil Section	--	0012	0009.5	0012	0009.5
	Equiv. Flat Plate Area	$ft.^2$	30.2	20.5	43.0	25.2
	No. of Eng./Eng. Designation	--	(2)T-58-8	(2)T-58-8	(2)T-55-L-5	(2)T-55-L-5
	Military Power Per Eng.	SHP	1250	1250	2200	2200
	Normal Rated Power Per Eng.	SHP	1050	1050	1850	1850
WEIGHTS	Rotor Group	lbs.	1749	1937	3030	3430
	Body Group	lbs.	2336	2403	3662	3890
	Landing Gear Group	lbs.	557	667	938	1220
	Flight Controls	lbs.	723	758	1021	1046
	Propulsion Group	lbs.	2875	2875	5218	5218
	Instr., Nav., & Aux. Power Plant	lbs.	135	135	282	282
	Hydr. Elect. & Electronics Group	lbs.	736	736	942	942
	Furn. & Equip. Group	lbs.	487	487	1015	1015
	Weight Empty	lbs.	9598	9998	16138	17043
	Useful Load	lbs.	5652	5652	9512	9512
	Fixed Useful Load	lbs.	459	459	662	662
	Fuel (100 N. Mi. Radius)	lbs.	2036	1850	3453	3069
	Pay Load (Outbound Only)	lbs.	3157	3343	5397	5781
	Gross Weight	lbs.	15250	15650	25650	26555
PERFORMANCE	Hover Ceiling @ 95°F, O.G.E.	ft.	6000	6000	6000	6000
	Max. Speed, Mil. Pow. S.L.	Knots	153	176	159	183
	Max. Speed, N.R.P., S.L.	Knots	147	170	152	176
	Speed For Best Range, S.L.	Knots	130	161	130	167
	Fwd. R/C, NRP, S.L.	fpm	2460	2175	2440	2330
	Ferry Range	n. mi.	1578	2160	1520	2100
	Assoc. G.W. For Ferry Range*	lbs.	25740	27200	41300	45300

* 500 FPM R/C @ S.L. NRP

Payload - Range Characteristics

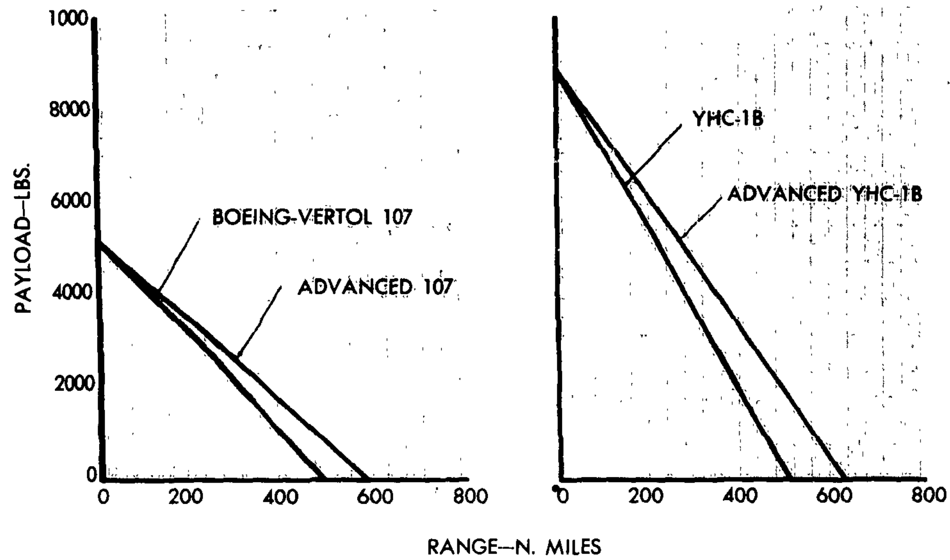
1. Vertol 107 Series.

Payload versus range is shown below for two takeoff gross weights. One of these is the gross weight as determined by the 6000 ft. 95°F hovering ceiling criterion and the other is the maximum alternate gross weight as determined by a forward rate of climb of 500 fpm at sea level with normal rated power.

PAYLOAD-RANGE

SEA LEVEL

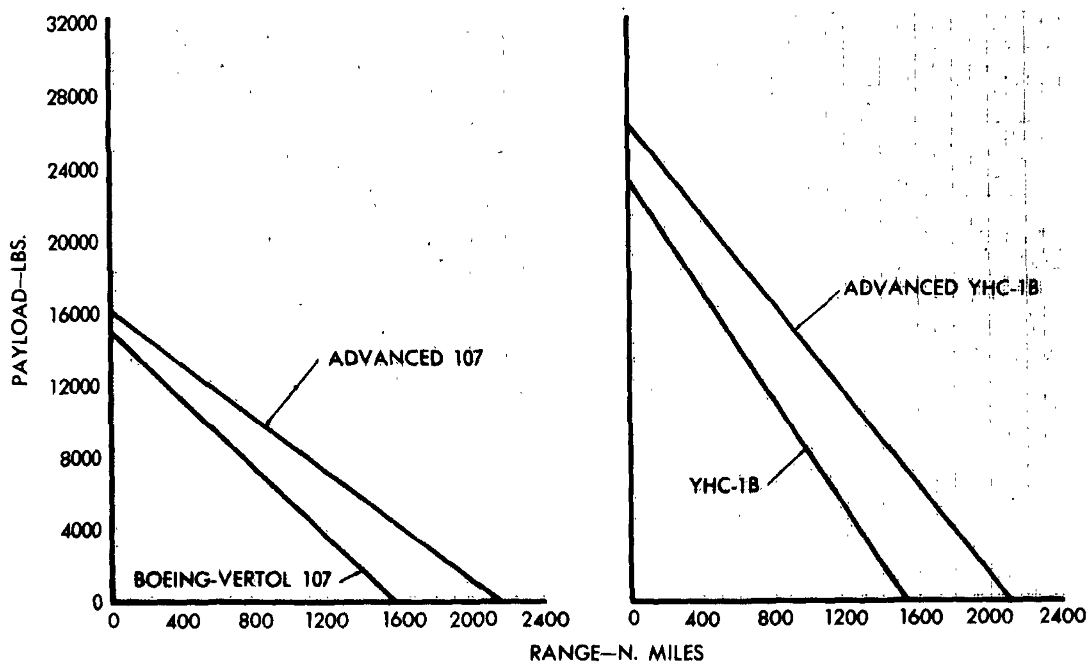
TAKE-OFF GROSS WEIGHT FROM 6000 FT. 95° F. HOVER CEILING



PAYLOAD-RANGE

10,000 FT.

TAKE-OFF GROSS WEIGHT FROM 500 FPM CLIMB AT SEA LEVEL



2. YHC-1B Series.

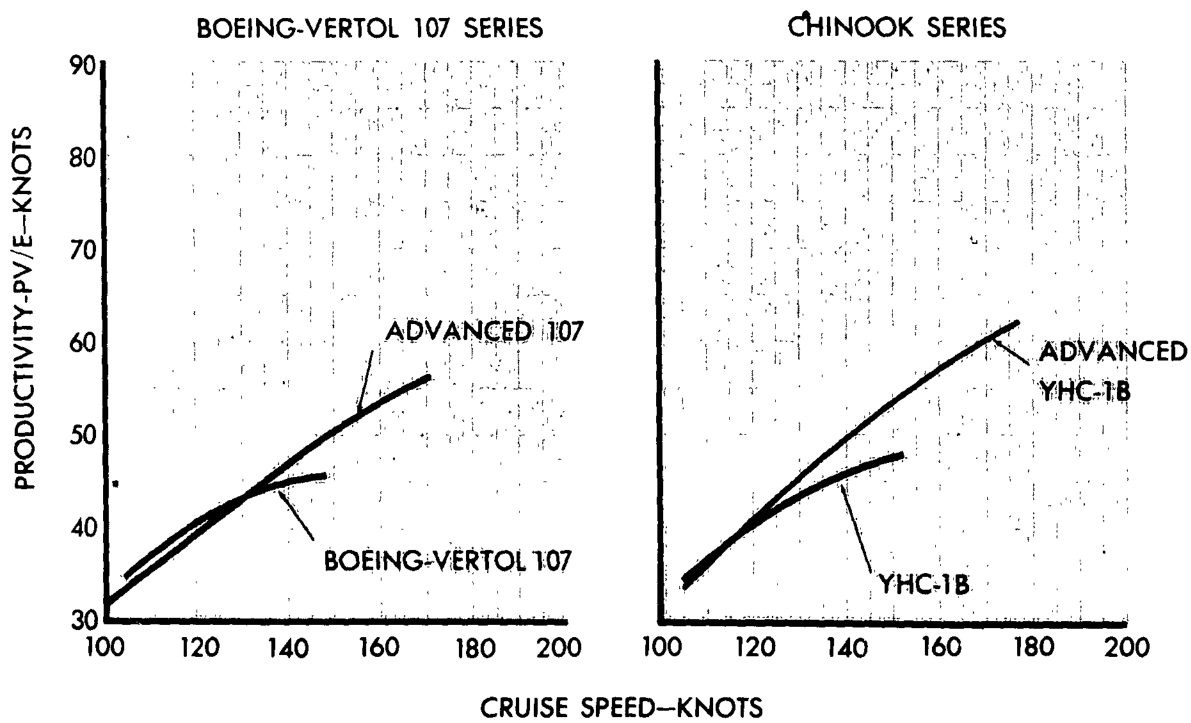
Range-payload characteristics, similar to those of the 107 series, are also presented. It is seen that the recommended configuration, the advanced YHC-1B, offers substantial improvement in payload-range and all-out ferry range.

Productivity

The transport efficiency of the 107 and the YHC-1B are shown in the following graphs in terms of productivity per pound of empty weight which is proportional to ton/nautical miles per dollar. It can be seen that the advanced version of either the 107 or YHC-1B results in substantial gains in productivity to empty weight.

PRODUCTIVITY VS. CRUISE SPEED @ SEA LEVEL

(100 N. MILE RADIUS)

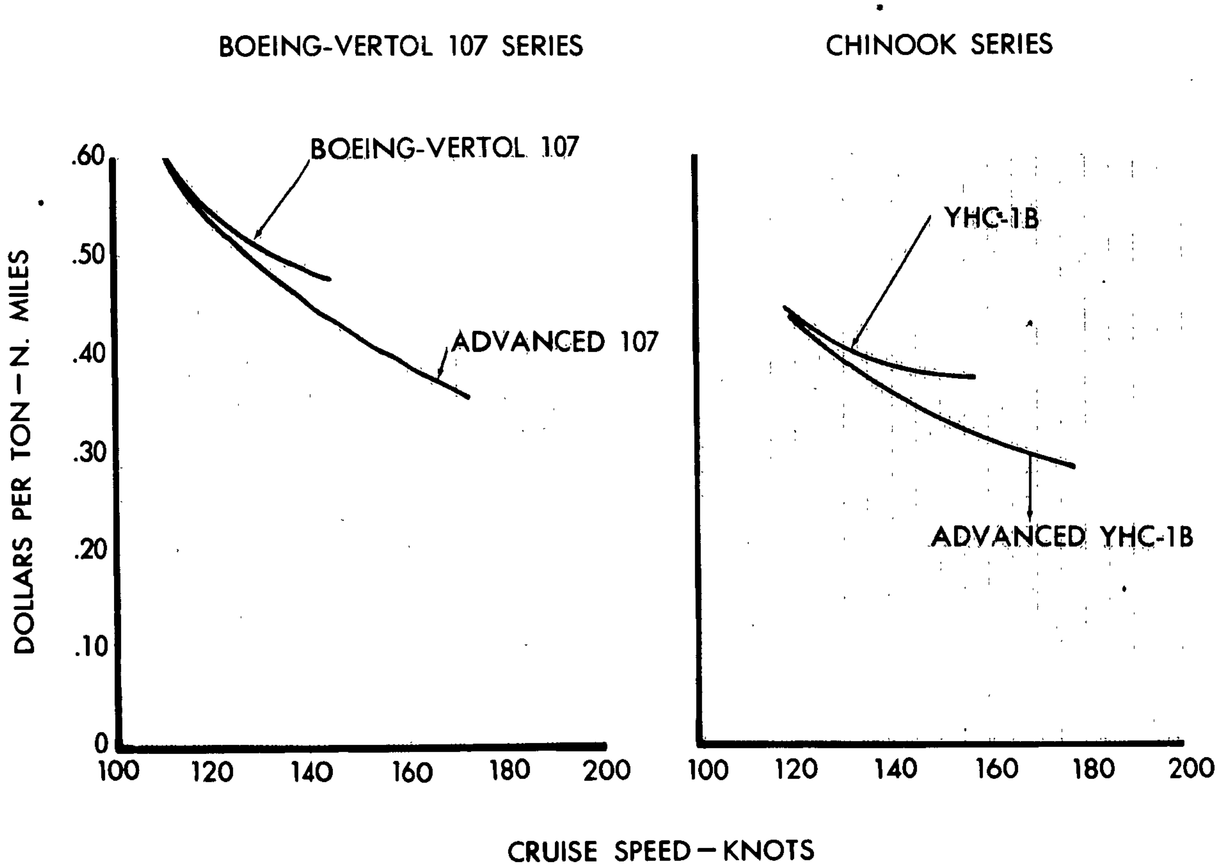


Maintainability

The maintainability, which is expressed in dollars of maintenance cost per ton/nautical mile, is presented for the Boeing-Vertol 107 and Chinook series. The maintenance dollars per flight hour was derived from studies of present helicopter operation extrapolated to turbine powered versions. Detailed maintenance analyses are discussed in Reference 1.

The high performance versions of either the 107 or Chinook result in decreased maintenance costs per ton/nautical mile at design cruise speeds in excess of approximately 130 knots.

MAINTENANCE COST VS. CRUISE SPEED



CONCLUSIONS

A review of the various means for achieving the increased performance with either the Boeing-Vertol 107 or YHC-1B helicopter has been made. The performance potential can be realized, using operational aircraft, by either increase in power available or increased rotor radius to reduce power required. The more efficient method with either helicopter is through radius increase which will have the secondary but important effect of further growth potential.

The high performance requirements may be achieved more economically and in a shorter development period with the current YHC-1B Army Chinook helicopter. The advanced YHC-1B will be capable of the inherent ferry range required for self-deployment and the increased cruise speed will result in a more efficient transport configuration.

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Unclassified Report

A preliminary design study has been conducted to establish a tandem helicopter configuration capable of the following minimum performance:
1) 1600 nautical miles ferry range at zero headwind with 1 hour fuel reserve. 2) 200 miles per hour speed with a minimum payload of 800 pounds. 3) Flying qualities to meet MIL-H-8501. Aerodynamic parametric studies and basic design layouts indicated that configurations derived from either the Boeing-Vertol 107 series or YHC-1B (Chinook) series could meet or exceed these performance requirements. Both blade radius and chord must be increased slightly, for either series, to insure that the ratio of payload to empty weight is maintained in going to the high performance configuration. Drag reduction and reduced blade loading were required

(Over)

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1. Summary, High Performance Helicopter Study

1. Harris, F.

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